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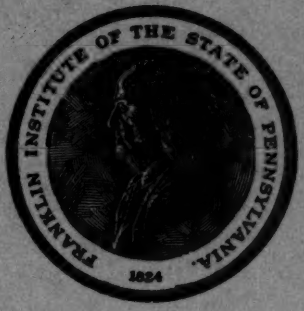
1826 

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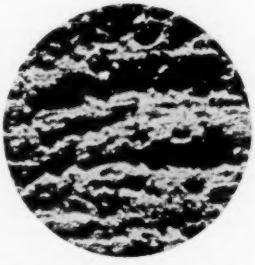

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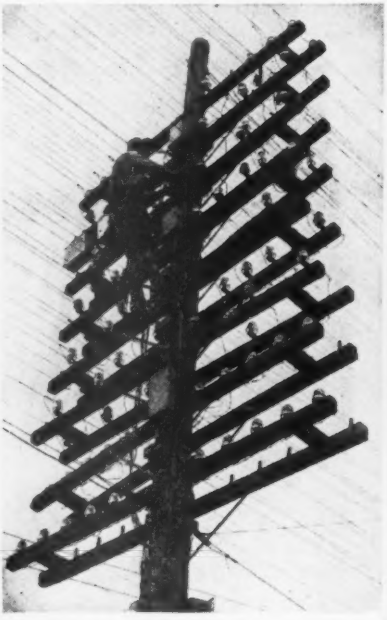

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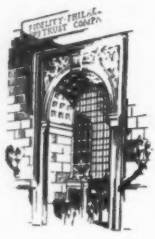

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CLIMATE CONTROL THROUGH IONIZATION*

BY

THOMAS L. MARTIN, JR.[1]

ABSTRACT

This paper summarizes some of the experimental evidence of the apparent biological effects produced by atmospheric ionization. Thermionic ion sources are discussed and the results of experimental determinations of their characteristics are presented.

BIOLOGICAL EFFECTS OF ATMOSPHERIC IONIZATION

It is a commonly accepted fact that weather and climate are the causes of biological and psychological effects in the human being. However, the factor, or factors, which cause these effects are shrouded in doubt, though there is considerable speculation.

For example, Dr. Edwin Grant Dexter, Professor of Education and Psychology at the University of Illinois, reports that misbehavior of children in schools and prison inmates is most frequent on hot and muggy days.

Another observation was made by neuropsychiatrist, Hans A. Reese, of the University of Wisconsin, who said, "Adequate and inadequate oxidation in cells and tissues is an important explanation to psychiatric disorders. And this is weather-linked, biochemically measurable, and clinically obvious."

Wind has nearly always been regarded as a contributing source of human ills, both physical and psychical. The *sirocco* of Sicily, *Solano* of Spain, *Zonda* of Argentina, and the *Föhn* winds of the Alps are all considered detrimental to either physical or mental health. However,

* Condensed summary of a research program instituted by the Wesix Electric Heater Co. at Stanford University.

[1] Associate Professor of Electrical Engineering, University of New Mexico, Albuquerque, New Mexico; and Consulting Engineer for Sandia Corporation (AEC), Albuquerque, New Mexico and Wesix Electric Heater Co., San Francisco, Calif.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

Dr. Dexter believes that wind by itself is not necessarily undesirable. Ill effects are apparently recorded only in cases of hot, dry winds.

An interesting point common to most of these studies is that interest centers primarily in purely "weather" factors, such as temperature, pressure, humidity, and wind. However, Dr. Manfred Curry (1)[2] prefers to distinguish between "weather" and climate. For example, he claims that while coastal California has beautiful weather, "That the climate is often quite miserable." He believes that weather is unrelated to health directly and prefers to make the distinction on the basis of good and bad climates. However, the health factor in climate is, as yet, not known specifically.

Dr. Curry's feelings on the subject of the the biological effects of weather and climate are shared by others, though their research and conclusions fall into different areas. Notable among these was Prof. Dessauer (2) who concluded that there is present in the atmosphere at least one other physical factor, in addition to temperature, pressure, humidity, and wind, which influences the dependence of man's health upon weather and climate. He, and others as well (3) suggested that this additional factor might be the ion content of the air.

Dessauer's experiments were conducted upon human beings using sub-microscopic MgO dust ions in concentrations of about 10^6 ions/cc. MgO was used since it was believed to be pharmacologically inert at the time of his tests. He reported clinical evidence of inhaling ions in this concentration as follows:

(1) Subjective effects
   (*a*) Positive ions produced feelings of nausea, fatigue, dizziness, and headaches.
   (*b*) Negative ions produced a feeling of exhiliration and well-being.
(2) Therapeutic effects
   Negative ions apparently relieved patients suffering from rheumatism, gout, arthritis, high blood pressure, asthma, hay fever, neuritis, neuralgia, bronchitis, and heat diseases.

More recent research indicates that negatively ionized air greatly inhibits the growth of transplanted tumors in rats and mice. Remarkable results were reported by Sokoloff, Eddy, Streltzoff, Bly, Williams, and Sciortino (3). They noted a similar inhibition of growth in spontaneous tumors as well as on benzpyrene-induced growth. The air was ionized by alpha-emitting radioactive polonium.

A preliminary report by John L. Worden (4) of St. Bonaventure College, discloses that the incidence of mold spores in the atmosphere was apparently reduced to 5 per cent of normal concentration when the air was ionized negatively with radioactive polonium.

Dr. Theodore Puck, biophysicist at the University of Colorado

[2] The boldface numbers in parentheses refer to the references appended to this paper.

Medical center, at the 1950 meeting of the American Chemical Society, disclosed that research he has been conducting indicates that viruses must carry electrical charges in order to attack living cells. If living cells were given charges through some other agency, the virus is believed to be incapable of becoming attached to the cell, and, therefore, unable to attack it.

Thus, it is clear that research in the biological sciences suggests that the electrical properties of the lower atmosphere may have an important bearing upon the health of man.

Under natural conditions, the electrical properties of the lower atmosphere are found to vary considerably. Atmospheric ions may be caused by radioactive materials in the air and earth surface and cosmic rays. These are the dominant sources in establishing the *mean* ion concentration. Large transient variations in ion concentration may be caused by drifting dust, falling snow, break-up of water into spray, and fire. Typical atmospheric concentrations are found to vary between about 500 ion pairs per cc. to as much as 2000 ion pairs per cc. In nearly every recorded case, the positive ion concentration exceeds the negative. Although there does not appear to be any world-wide seasonal variation in atmospheric ion concentrations, it is found that the positive ion concentration is largest around cities, where atmospheric contamination is great, and least in the country and at sea.

The wide latitude of variation in atmospheric ion concentrations from time to time and place to place makes biological experimentation of the effects of atmospheric ionization rather difficult. Thus, a real need exists, if this research is to be furthered, for artificial, controlled ion sources that can produce ions in air of either polarity and at controlled rates.

ARTIFICIAL ION SOURCES

If the ion concentration of the air is accepted as a possible contributing factor in the "climate" effect upon man's health, then artificial ion sources probably represent mankind's first effort to control "climate" without controlling weather.

The artificial methods of producing ions in the atmosphere may be listed as follows:

(1) thermionic ion generation (hot wires),
(2) ionization by high speed particles (use of radioactive materials),
(3) x-rays,
(4) ultra-violet photo-ionization,
(5) high voltage brush discharge,
(6) high frequency.

Any method which produces ozone or the oxides of nitrogen as by-products is undesirable from the biological viewpoint. Moreover, any method which causes physiological effects directly is unsatisfactory,

since this would obscure the effects produced by ionization. Consequently, from the practical standpoint, only hot wires and alpha-emitting radioactive materials appear to be suitable for general use.

The physical characteristics of thermionic ion sources are partially summarized in the next section. These tests were made by the author on a research project at Stanford University sponsored by the Wesix Electric Heater Co., of San Francisco. A similar study is under way on radioactive ion sources at the University of New Mexico.

THERMIONIC ION GENERATION IN AIR

A schematic diagram of the ion test tube is shown in Fig. 1. All elements of the main tube structure were supported by a solid polystyrene bar (part No. 12) 11 in. long and 1 in. in diameter. This pro-

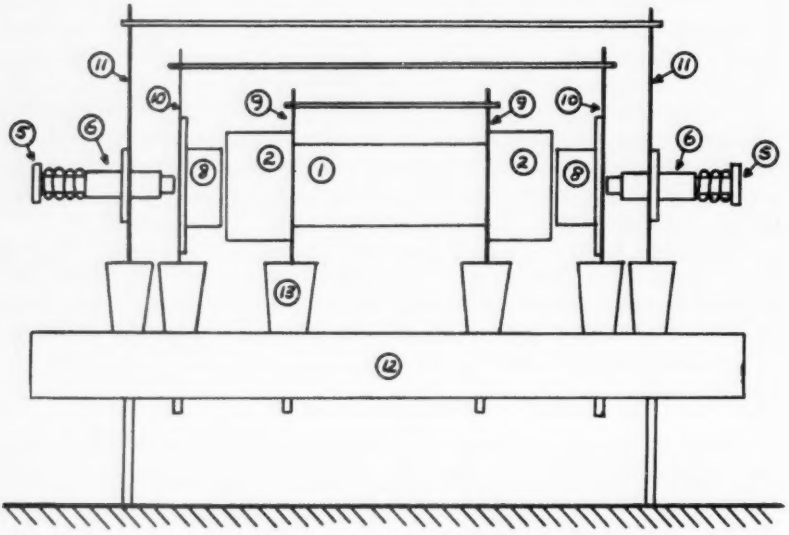

FIG. 1. Schematic drawing of M-3 ion test tube.

vided the main electrical insulation between the elements of the ion tube. Six porcelain insulators (parts No. 13), used to insulate the polystyrene from the heat of the metallic components, were bolted to this base. Thin aluminum plates (parts 9, 10, 11) were bolted to the other ends of the six porcelain insulators. These plates were mechanically connected in pairs by spacer rods. The thin metal sheets act as supports for the main anode (part Nos. 1 and 2), the guard rings (parts 8), and the lead guides (parts 6). The filament lead (part 5) slides through the lead guide, being held in place by the tension of the filament and a small helical spring on each lead. The main anode and guard rings are cylindrical. The filament is coaxial with them. Current to the main

anode only was measured. This constituted a measurement of the ion current from 5.25 in. of wire. All tests were conducted on wire having a diameter of 0.020 in.

Tests were conducted on both positive and negative ion currents generated thermionically in air at normal pressure by the following filament material: (1) nickel, (2) platinum + 4 per cent tungsten, (3) platinum + 20 per cent rhodium, (4) platinum, and (5) nichrome V. Generally speaking, the characters of the results obtained for all five materials were essentially the same. There were remarkable differences in magnitudes of currents, but the *shapes* of the curves obtained in various tests were substantially independent of the filament material. There were some differences that may or may not be significant, but

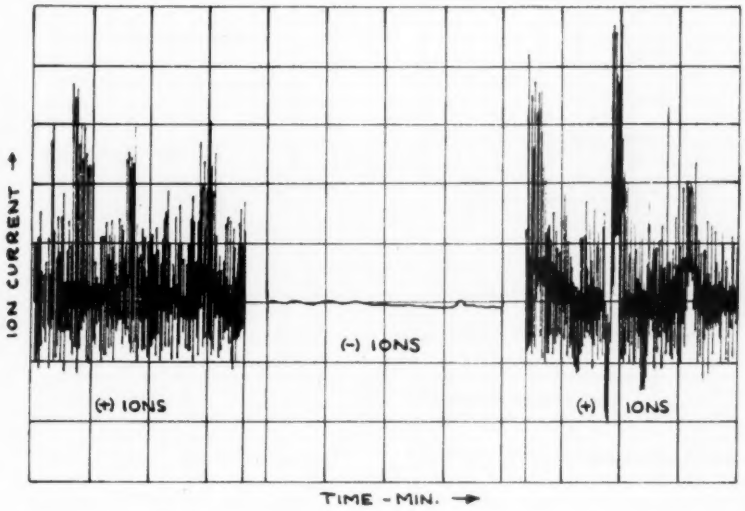

FIG. 2. Difference between the character of positive and negative ion currents.

limitations of space in this article require that only representative, relatively general results be submitted.

One of the most significant and startling results obtained is illustrated in Fig. 2 which shows "steady state" saturation positive and negative ion currents as a function of time. It is clear that the characters of the ion currents are remarkably different. The negative ion current is relatively stable and continuous over short observational periods of about a minute or so. However, the positive ion current differs from this comparatively stable negative ion current in that a highly variable, purely random component of current appears superimposed upon a relatively steady component. The author calls this variable component the positive ion *noise* current.

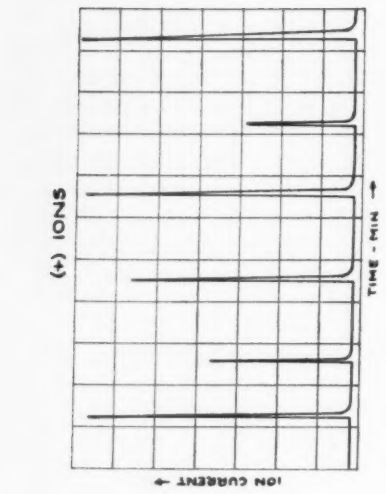

FIG. 4. Effect of smoke on ion current due to a platinum filament.

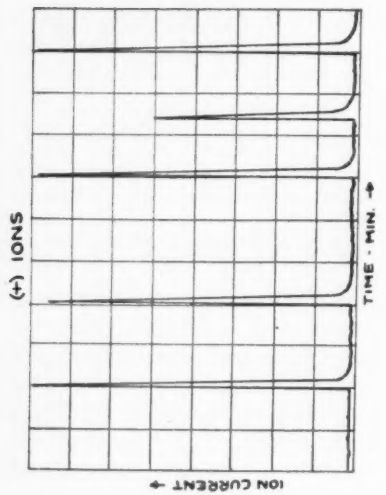

FIG. 3. Effect of smoke on ion current due to a nichrome V filament.

The noise component of the positive ion current seems to be independent of the filament material, the filament temperature (as long as it is above 1000°C.), the past thermal history of the filament, and the electric field intensity at the filament surface. Due to this independence of all of the factors that normally govern the emission of electricity from hot bodies, it is believed that the positive ion noise component is not an emission current, but is produced by the ionization of certain atmospheric impurities when they strike the hot filament. If this proves to be true, possible applications of the phenomenon exist in the removal of atmospheric impurities such as smog, smoke, and pollens and in the measurement of atmospheric pollution.

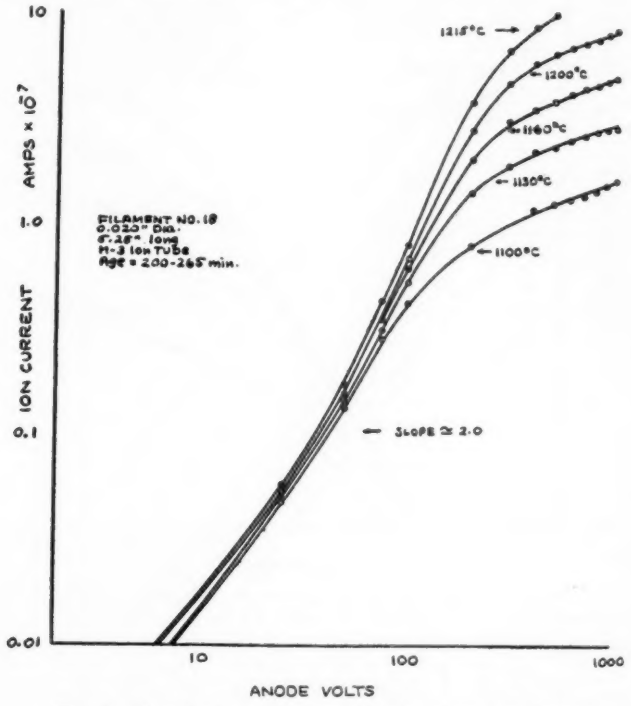

FIG. 5. Negative ion current as a function of anode voltage.

There is some supporting experimental evidence of the supposition made in the preceding paragraph. For example, a few preliminary tests were conducted by the author by introducing small quantities of smoke into the interelectrode space of the ion tube. The results were extremely interesting and representative samples are shown in Figs. 3 and 4. A nichrome V filament was used to obtain Fig. 3 while platinum was used for Fig. 4. In both cases, the introduction of a small amount of smoke

caused the positive ion *saturation* current to increase tremendously, while the negative ion saturation current decreased in the case of a nichrome V filament and increased when platinum was used.

Further tests were conducted by establishing operating conditions so that the ion current was space charge limited. In this case, the introduction of smoke caused the ion current to decrease for both ion polarities and for both filaments. This result was anticipated since

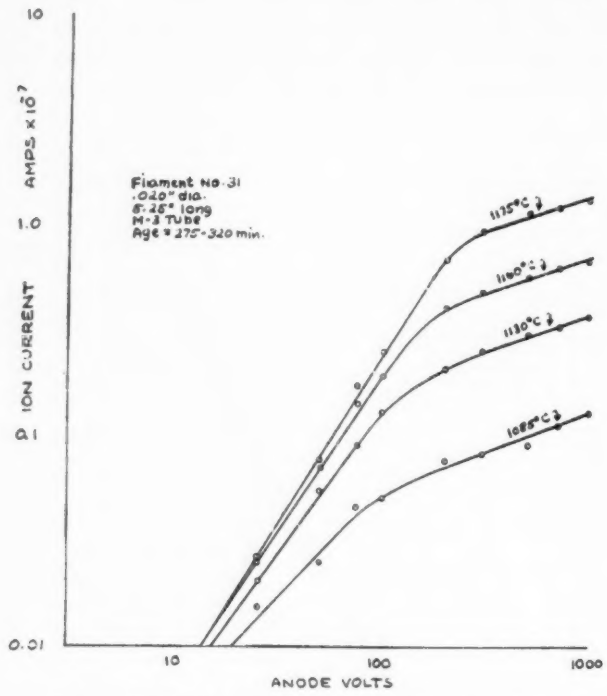

FIG. 6. Positive ion current as a function of anode voltage.

the space charge limited ion current can be shown to be approximately

$$i_b = C_1 K E_b^2,$$

where

i_b = ion current,
C_1 = constant dependent upon tube geometry,
K = ion mobility, and
E_b = anode-to-cathode voltage.

Apparently the smoke molecules become attached to the ions, thereby decreasing the ion mobility and ion current. However, the cause of the unusual results obtained with saturation ion currents is unknown.

The validity of the theoretical equation for the space charge limited ion current

$$i_b = C_1 K E_b^2$$

is evident from Fig. 5. Here the negative ion current has been plotted against E_b on log-log paper. In nearly all such cases, a slope of 2.0 was obtained over a range of values of E_b. This is clearly the space

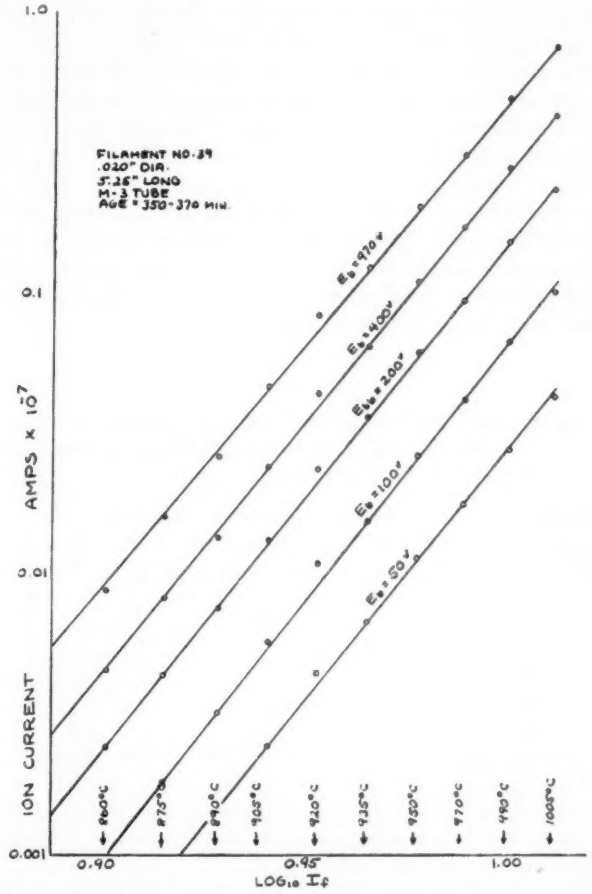

FIG. 7. Negative ion current as a function of filament heating current.

charge limited region. Similar results were obtained with positive ion currents, but over a considerably smaller range of voltages, E_b. Small deviations from the value of 2.0 for the slope are believed to be due to ion mobility changes caused by increased ion "life," when the density of the space charge is increased.

Reference to Fig. 5 shows that the negative ion current does not become constant when saturation is reached, but continues to increase as the anode voltage is increased. This is apparently evidence of a pronounced Schottky effect. The effect was observed for negative ion currents due to all five filament materials. A similar phenomenon was found to exist for the steady component of the positive ion current due to all filament materials except nickel, but where it exists, the effect is rather more complicated than predicted by the basic Schottky theory. It is possible that the effect was present with a nickel filament as well, but the noise component of positive ion current was so large that it may have obscured the Schottky effect upon the steady component A typical result for positive ion current *vs.* anode voltage is shown in Fig. 6.

Data were also obtained to plot ion current as a function of filament heating current with anode voltage as the parameter. When the data for negative ion current are plotted on log-log graph paper, the resulting figures are very nearly straight lines, as shown in Fig. 7, as long as there are no space charge effects. Thus, to a close approximation, the negative ion saturation current depends upon the filament heating current, I_f, according to the following equation:

$$i_b = C_m I_f^a,$$

where

C_m = constant depending upon the anode voltage, filament material, and past thermal history of the filament, and
a = slope on log-log paper.

Typical values for the slopes are given in Table I. The value of a varies slightly with the past heat treatment of the filament, but few variations in excess of 5 per cent of the values in Table I were observed.

TABLE I.

Material	a
Nickel	1.33
Platinum + 4% tungsten	2.1
Platinum + 20% rhodium	2.0
Platinum	2.6
Nichrome V	1.25

Since platinum exhibits the largest value for a, it is the most sensitive to changes in filament heating current.

The dependence of the steady component of positive ion current upon filament heating current is illustrated in Fig. 8. In this case, the data yield curves consisting of two, essentially straight, line segments on log-log graph paper. Typical values for the slopes of these line segments and the temperature at the "break point" between segments, are given in Table II for the platinum metals. These figures are subject to considerable variation with the past heat treatment of the filament.

Data are not submitted for nichrome V and nickel because the high noise component made accurate measurements of the steady component very difficult.

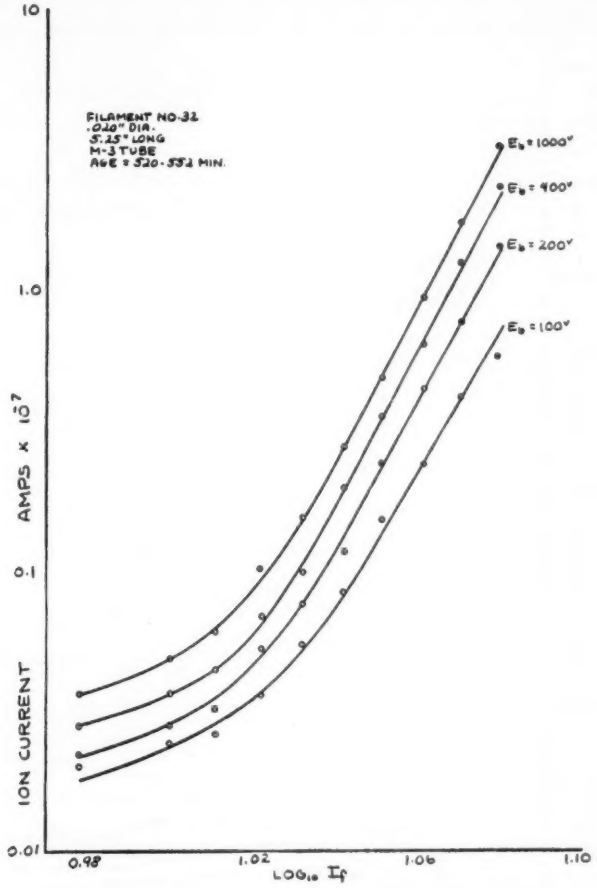

FIG. 8. Positive ion current as a function of filament heating current.

TABLE II.

Material	Max. Slope	Min. Slope	Break Pt. Temp., deg. C.
Platinum + 4% tungsten	2.1	0.50	1100
Platinum + 20% rhodium	2.0	0.37	1060
Platinum	1.2	0.33	1020

Deviations from the straight line character of the foregoing curves are apparently due to space charge effects. There is an interesting aspect to this problem illustrated in Fig. 9. Here the negative ion current is plotted as a function of filament heating current on linear graph paper. Over the saturation part of the curve the current increases continuously

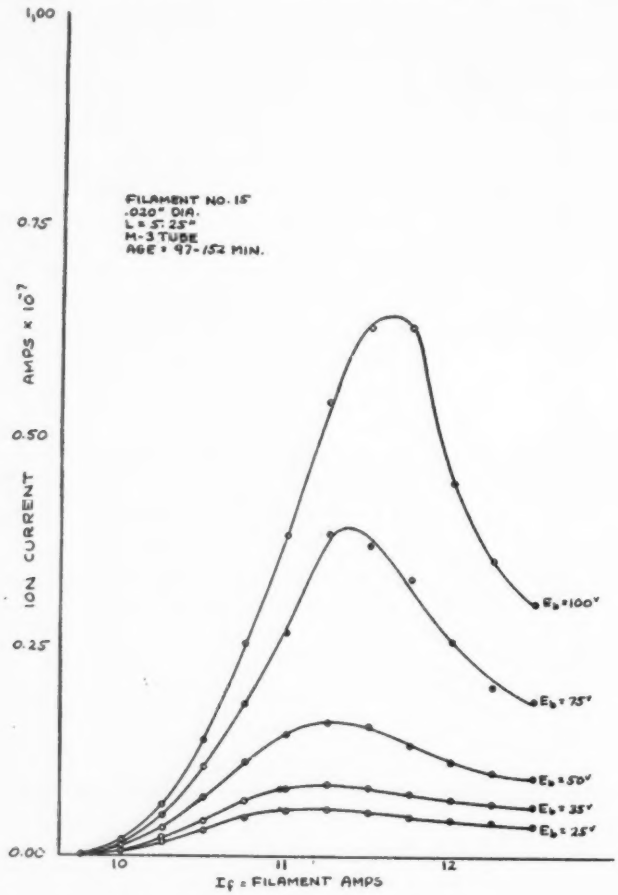

FIG. 9. Effect of space charge on ion current.

with increasing I_f. But, when space charge limiting sets in, a curious thing occurs: the ion current *decreases* as the heating current is increased. This effect is apparently caused by the fact that an ion may circulate around in the space charge cloud for a short while, depending upon the ion density, before being collected by the anode. In general, an increase

in ion "age" will decrease its mobility, K, and thereby decrease the space charge limited current. The same effect occurs with positive ions.

The variations in the positive ion currents of all five filament materials as functions of time were essentially the same. When a fresh filament was heated, the current dropped extremely rapidly over a period of a few minutes and then levelled off. The ion current continues to decrease thereafter, but at a much slower rate. A typical result is shown in Fig. 10. If the filament is allowed to cool for 30 seconds or more and then reheated, a similar result is obtained: a precipitous drop followed by a slow decrease. However, in this case, the initial drop occurs over an interval dependent upon the cooling interval

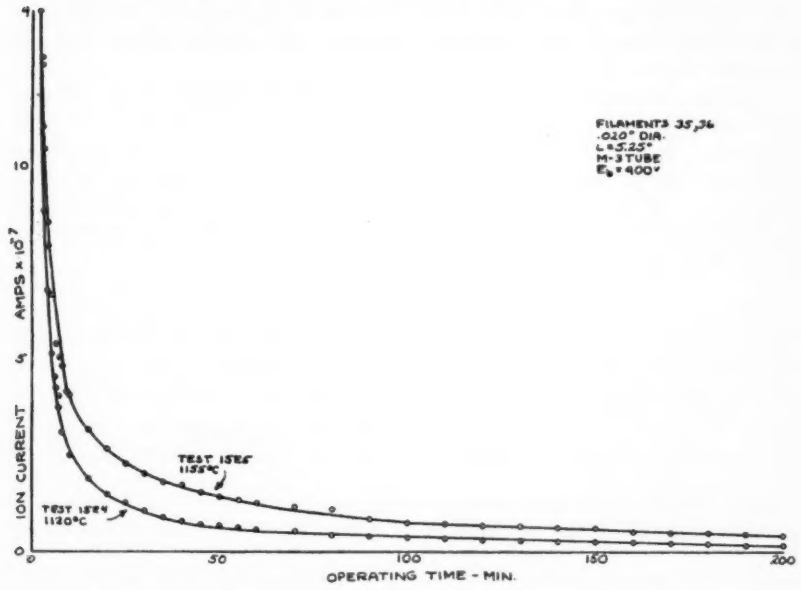

FIG. 10. Positive ion current as a function of operating time.

of the filament. It appears that this may be due to occluded gases in the filament.

The negative ion current varied in a different way as a function of time. For nickel and nichrome V, the negative ion current dropped extremely rapidly during the first few minutes and then levelled off somewhat and decreased much less rapidly. However, the negative ion current due to the platinum metals increased gradually during the first 10–20 minutes and then decreased at a slow, but continuous rate. This type of curve was not duplicated if the filament was allowed to cool for 1–3 minutes and then re-heated.

CONCLUDING REMARKS

The experimental results described in the preceding section clearly indicate two important points:

1. Thermionic ion sources are difficult to design and control for use in biological experimentation. Insufficient data are available to permit proper design. Moreover, the effects that may be caused by atmospheric pollution components are not known with sufficient accuracy nor is this contamination under control. Consequently, pending the accumulation of more data, it appears that while thermionic agencies can produce ionized air of either polarity, they are not suited to experimental work. As a result, a research project has been instituted by the Wesix Electric Heater Co. in the Electrical Engineering Department of the University of New Mexico to study and design radioactive ion sources.

2. Electric heaters are sources of ions of either polarity in an amount determined by many factors. In view of the results of biological experimentation described in the first article, this may be undesirable or desirable, depending upon the polarity of the ions and the amount produced. It is possible that a *properly designed* electric heater may well produce therapeutic effects as well as thermal effects and this may be the first step toward *climate control.*

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COMPENSATION OF FEEDBACK-CONTROL SYSTEMS SUBJECT TO SATURATION *

BY

GEORGE C. NEWTON, JR.[1]

Part I [2]

ABSTRACT

A theory for the design of compensating networks for feedback-control systems and filters is developed herein. The novel feature of this theory is its consideration of saturation and transient performance in addition to the usual steady-state behavior. This theory is essentially an extension of the researches of Wiener and Lee in statistical methods for filter design. Saturation is handled by limiting the rms. signal levels at critical points in the linear model used as the design basis for the physical system. Transient performance is handled by limiting the integral-square errors to a set of transient tests signals.

I. BACKGROUND AND OBJECT

Modern feedback-control systems are usually designed by a combination of analysis and experiment. This paper is confined to certain of the analytical aspects. In order to reveal the object of the investigation herein reported, the important analytical methods in current use will first be reviewed.

Compared with an elementary filter, a continuous feedback-control system involves two additional complications: the first, a partially or completely specified output device (servomotor or process); and the second, one or more independent or semi-independent disturbing variables (load torque, for example). In common with the filter, the feedback-control system often is called upon to separate data from noise. However, because of the restrictions upon the output device, the designer of a feedback-control system has free choice of the remaining equipment only. For this reason, feedback-control designers often regard their problem as one of compensation design.

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* This paper is abstracted from the theoretical portion of a thesis presented to the Massachusetts Institute of Technology in partial fulfillment of the requirements for the degree of Doctor of Science in Electrical Engineering. The basic problem of dealing with saturation in feedback-control systems has arisen repeatedly in the author's experience in the automatic control field. A partial solution was obtained during work for the Fairchild Guided Missile Division, Fairchild Engine and Airplane Corp. under Navy Contract NOa(s) 9020. The more general solution contained in this paper was obtained in the course of research conducted in the Servomechanisms Laboratory at M.I.T. under Air Force Contract W33-038ac-13969.

The author is indebted to Drs. G. S. Brown, A. C. Hall and Y. W. Lee of the Massachusetts Institute of Technology for their sponsorship of this research. He wishes to thank his colleagues at the Massachusetts Institute of Technology for their constructive criticism of the research and its reportings.

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[2] Part II will appear in this JOURNAL for November, 1952.

The analysis of compensation for feedback-control systems is firmly rooted in the mathematics of linear systems (1)[3]. In order to make appreciable analytical progress it is common practice to replace an actual system by a mathematical model which is linear and which, element by element, represents closely the actual system as long as signals are restricted to the so-called linear ranges. After introducing the linearity assumption, the most common procedure is to analyze the behavior of a number of tentative designs and select the best. Usually the frequency-response method of analysis is employed and rather standardized compensation schemes are tried (2) (lead-networks, integral networks, parallel feedback through filters, etc.). This trial and error approach is analogous in some respects to conventional filter theory with its standardized "constant-k" and "m-derived" sections. Recently, attempts have been made to apply modern network theory to feedback-control system design (3).

A statistical theory for the filter and feedback-control problems was presented by Dr. N. Wiener in 1942 (4). This theory, as extended by Dr. Y. W. Lee (5) and others, determines the compensation necessary to minimize the rms. error between the desired output and the actual output. It is found that the input autocorrelation and input-desired output cross-correlation functions, in addition to the impulse response of the output device, completely determine the impulse response of the compensation equipment. To the author's knowledge this is the first example in the communications field of a direct design theory—one which goes from problem specifications to solution in a direct analytical manner without recourse to trial and error methods in some form.

When the results of the above mentioned linear design theories are put to laboratory test, one or both of the two difficulties often may be encountered. The first difficulty is saturation of one or more elements in the output device. That it is possible to encounter such a difficulty is readily appreciated when one considers the implications of linearity. According to linear theory there is no limit to the frequency response of a system consisting of a compensating network cascaded with a fixed network, providing the latter is minimum phase and the input to the system is noise free. It is only necessary to provide a compensating network with a frequency response which is the reciprocal of the response of the fixed network. In this way an electric motor which cuts off at 1 cycle per second theoretically can be made to follow exactly a 1000 cycle per second signal of any amplitude. But a 1000 cycle per second signal of more than a very minute amplitude would surely saturate a physical motor, especially in view of the effect of the compensating network used. Similar considerations hold for the more general situation of systems subjected to noise-polluted inputs. *Saturation, therefore, often is an important limitation on the performance of feed-*

[3] The boldface numbers in parentheses refer to the references appended to this part of the paper.

back-control systems. Linear design theory, *per se*, has taken little account of saturation up to the present time.

The second difficulty met in practice is related to the transient behavior of systems. Recently, linear theory has concerned itself primarily with procedures based on steady-state frequency-response analysis or steady-state statistical procedures. In practice, systems are frequently called upon to switch modes of operation, with the result that some importance is attached to transient behavior. In order to cope with such practical problems it would be highly desirable if a design theory could be developed to embrace both steady-state and transient behaviors.

The object of the work reported here is the development of a modified linear design theory for feedback-control systems (and filters) which takes into account saturation and transient performance. The theory developed here is essentially an extension of the theories of Wiener and Lee and in common with them postulates the rms. error criterion.

II. SCHEME FOR CONSIDERING SATURATION

Two very different approaches to the saturation question are conceivable. One approach is to regard a combination of linear and saturating elements as an essentially nonlinear system. This approach immediately requires nonlinear methods and thereby suffers from the lack of generality characteristic of these methods. The work of Hurewicz and Nichols (6) may be cited as an example of this approach in the design of servomechanisms. A second approach is to view a combination of linear and saturating elements as an essentially linear system. By appropriate design of the linear portions of the system it is conceivable that operation of the saturating elements in their nonlinear ranges may be largely avoided. If this can be done, then linear methods may be used, thereby introducing great generality after once accepting the initial restriction of operating the saturating elements substantially within their linear ranges only. An application of this second approach to the design of servomechanisms for transient and periodic operation has been made by Travers (7).

The meaning of saturation in this paper is more closely defined by reference to Fig. 1, which shows a typical excitation-response curve for a saturating element. In linear analysis, saturating elements are replaced by linear models which possess excitation-response curves which are related to those of the corresponding saturating elements in the manner indicated by the dashed, sloping line in Fig. 1. Throughout this paper all analytical work is based upon the *fictitious linear system* obtained from the actual system by replacement of all of the actual saturating elements with their linear models. This fictitious system will be so designed that the root-mean-square response amplitude for each linear model representing a saturating element in the actual system is maintained below specifiable limits. That this is useful

derives from the basic assumption of this scheme for treatment of saturation, *viz.*:

Basic assumption in the treatment of saturation used in this paper.

In the fictitious linear system obtained by replacing the saturating elements of the actual system by their linear models, limiting the rms. responses of these linear models is effective in limiting the probabilities that the responses of the saturating elements of the actual system exceed the linear ranges characterizing these elements.

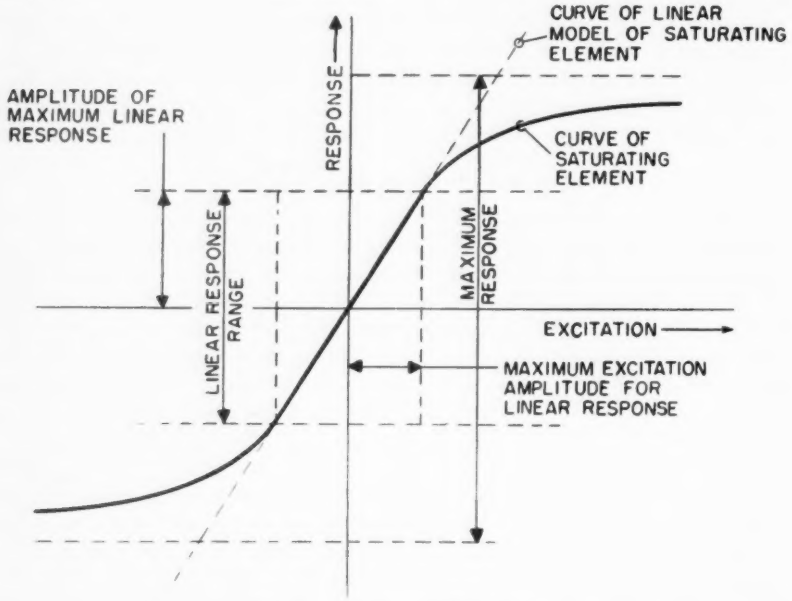

FIG. 1. Typical saturation curve.

This assumption in no way presupposes known relationships between rms. responses in the fictitious system and the probabilities of saturation in the actual system. The exact determination of these relationships would require a nonlinear analysis involving the probability density curves for the input signals and the exact knowledge of the characteristics of all the nonlinear elements. Such an analysis is obviously extremely complex and is just what we are trying to avoid by use of the premise. The basis for the premise must be primarily empirical in the sense that its use leads to system designs in which the experimentally observed actual probabilities of saturation are indeed controlled by limitation of the rms. responses in the fictitious linear system used as a basis for design. Some experimental work for one case of

interest has already been carried out in order to establish design figures relating probability of saturation in an actual system to rms. response in the fictitious linear system used in its design (8).

Secondarily, there is an intuitive basis for this premise obtained by extrapolation from the following simple example. Imagine a cascaded group of elements forming a filter which contains only one saturating element. Suppose this filter is driven by a signal which results in an excitation amplitude for the saturating element which has a normal (Gaussian) probability density curve. Such signals are met in practice, particularly in situations where the signal is a composite signal formed from many random sources. The response for the linear model of the saturating element in the fictitious linear system is obviously normal.

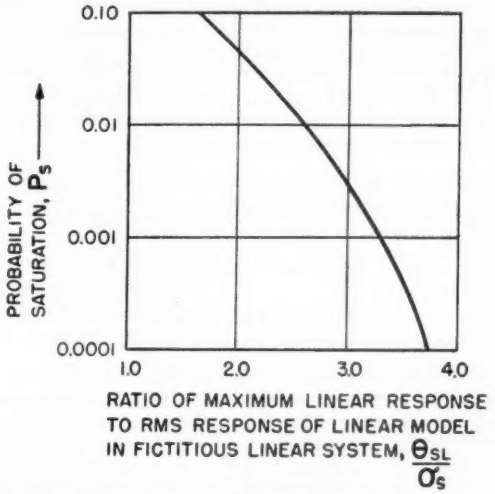

FIG. 2. Probability of saturation in simple filter having one saturating element only when driven by signal which produces an excitation for saturating element which has normal probability density curve.

The probability of finding the actual response of the saturating element outside of the linear range is rigorously defined in this case. Let

$\theta_{SL} \triangleq$ maximum linear response of the saturating element,

$\sigma_s \triangleq$ rms. response of the linear model of the saturating element in the fictitious linear system,

$P_s \triangleq$ probability of finding the actual response outside the linear range.

Then for this case

$$P_s = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\frac{\theta_{SL}}{\sigma_s}}^{+\frac{\theta_{SL}}{\sigma_s}} \frac{dy}{\sigma_s} e^{-\frac{y^2}{2\sigma^2}}. \tag{1}$$

A plot, for this case, of the probability of saturation P_s as a function of the ratio θ_{SL}/σ_s is shown in Fig. 2.

This plot shows that, for the normal distribution, the probability of saturation is a rapidly decreasing function of the maximum linear response for a fixed rms. excitation. Plots for other distributions which may be met in practice generally would be expected to show similar rapid decreases of the probability of saturation after certain values of maximum linear response are exceeded. We thus observe for the simple filter having only one saturating element that little doubt exists concerning the validity of the basic assumption.

Once the basic assumption for treating saturation is made, thereby linearizing the design problem, it follows immediately that the filter and feedback control problems are equivalent. Figure 3 shows a block

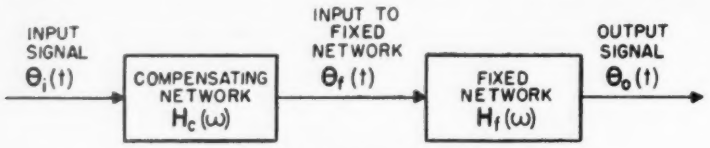

FIG. 3. Block diagram of filter system.

diagram of the filter in which $H_c(\omega)$ is the system function of the compensating network and $H_f(\omega)$ is that of the fixed network. The over-all system function is

$$H(\omega) = H_c(\omega)H_f(\omega). \tag{2}$$

Figure 4 shows a block diagram of the feedback-control system in which

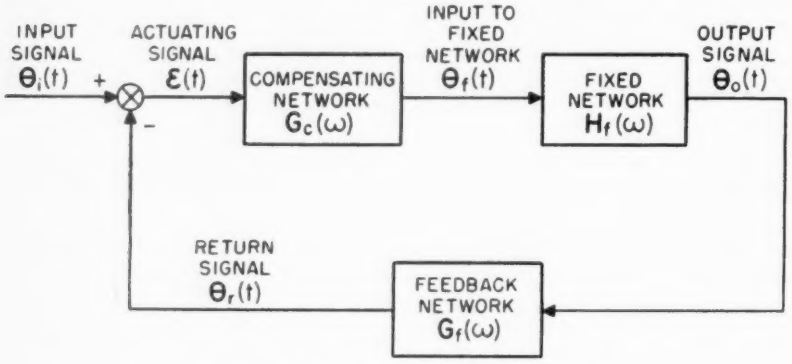

FIG. 4. Block diagram of feedback-control system.

system functions are designated as $H_f(\omega)$ for the fixed network or output device, $G_c(\omega)$ for the compensating controller, and $G_f(\omega)$ for the feedback network. The over-all system function is

$$H(\omega) = \frac{G_c(\omega)H_f(\omega)}{1 + G_c(\omega)H_f(\omega)G_f(\omega)}. \tag{3}$$

(Note that discussion in terms of system functions is possible solely because of the linearization permitted by the basic assumption concerning saturation.) Since only stable systems are of interest, stability considerations show that the feedback-control configuration can achieve no result which cannot be achieved by the filter arrangement in the case of stable fixed networks. Thus, for stable fixed networks, the designer may choose at his convenience either the filter or feedback-control arrangements for design purposes. In the derivations of this paper, the filter configuration is simpler to use. After obtaining $H_e(\omega)$ for the filter, $G_c(\omega)$ and $G_f(\omega)$ for the feedback-control arrangement may be determined so as to provide equivalent effective cascade compensation. In case of an unstable fixed network, the use of auxiliary feedback frequently enables stability to be obtained. By using the unstable fixed network with auxiliary feedback as the stable fixed network in the design of an equivalent filter, the solution for the complete feedback-control system may be obtained.

The argument for the equivalence of the filter and feedback-control problems has omitted mention of disturbing variables such as load torques. It can be shown that the problems involving disturbing variables introduced at points inside or on the boundaries of the fixed network can be reduced to the fundamental problem involving only input, actual output, and desired output. For this reason no special consideration to disturbing variables is given here.

III. SCHEME FOR CONSIDERING TRANSIENT PERFORMANCE

Transient performance refers to the ability of a system to respond in some desired fashion to an input signal which is neither periodic nor stochastic, but which is a definite function of time which is aperiodic within an infinite range of time. Such input signals are called transient signals. The unit step function is a typical example. A transient input function will be denoted by $C_i(t)$. When the signal $C_i(t)$ is applied to the system, the desired response will be defined as the function $C_d(t)$.

How should the transient performance of the system be measured? If the system output $C_o(t)$ existing for the input $C_i(t)$ is exactly equal to the desired output $C_d(t)$, then there is no question but that the transient performance is "ideally" perfect. The difference, $C_d(t)-C_o(t)$, will be designated by the function $C_e(t)$. It is apparent that this difference function is a measure of the departure of the actual performance from the ideal. However, it is a complicated measure since it is a function of time. In order to simplify the measure, the integral-square value of $C_e(t)$ will be adopted. We define the integral-square transient error I_e as

$$I_e = \int_{-\infty}^{\infty} dt C_e^2(t). \tag{4}$$

In this manner a single number is arrived at which characterizes the transient performance of the system for a given disturbance.

The use of the integral-square error as a measure of the transient performance of a system is justified on the basis of expediency. Any other criterion that has been devised appears to involve greater difficulties in its mathematical formulation. The integral-square error has been used before in a different connection as a measure of the transient performance of systems by Hall (9).

In the formulation of the compensating-network design problem used in this paper, K pairs of transient-input and desired-output signals with K corresponding integral-square errors will be considered. These will be designated as $C_{ik}(t)$, $C_{dk}(t)$, and I_{ek}, respectively, for the kth transient-input function or test signal, the kth transient desired-output function, and the integral square of the kth error $C_{ek}(t)$.

Basic scheme for accounting for transient performance. The basic scheme for bringing transient performance considerations to bear in the design of compensating networks will be to so design these networks that the over-all system produces, for K pairs of specified transient-input and desired-output functions, integral-square errors equal to or less than specified limits I_{emk}. The limitation of integral-square errors for a number of transient test signals is the fundamental idea used to inject transient-performance considerations into the compensating-network design problem.

IV. RESULTS OBTAINED

A. The Mathematical Problem

In view of the schemes presented in the two preceding sections for treating saturation and for introducing transient-performance considerations, the problem of designing a compensating network can be formulated mathematically, if certain additional assumptions are made. These assumptions are four in number:

1. The normal input and normal desired output are both functions of time possessing suitable correlation functions.
2. The desired output is related to the input (or a portion of the input such as a message component).
3. The transfer characteristics of the fixed network are known, including the over-all transfer characteristic and the transfer characteristics through to the responses of the linear models of the saturable elements of the actual fixed network.
4. The optimum compensating network is the one that minimizes the rms. error between the normal desired output and the normal actual output. The compensating network is to be built so that no saturation

occurs within it. (The adjective "normal" is used to distinguish the several signals of the system when under the normal excitation of a stochastic input signal from these same signals when the system is actuated by a transient-input test function for the purpose of transient-performance determination.)

The first three assumptions are generally not very restrictive. The fourth assumption, however, is sometimes a questionable one. Some problems do exist where minimizing the rms. error is equivalent to maximizing success in terms of more meaningful criteria (10). Other

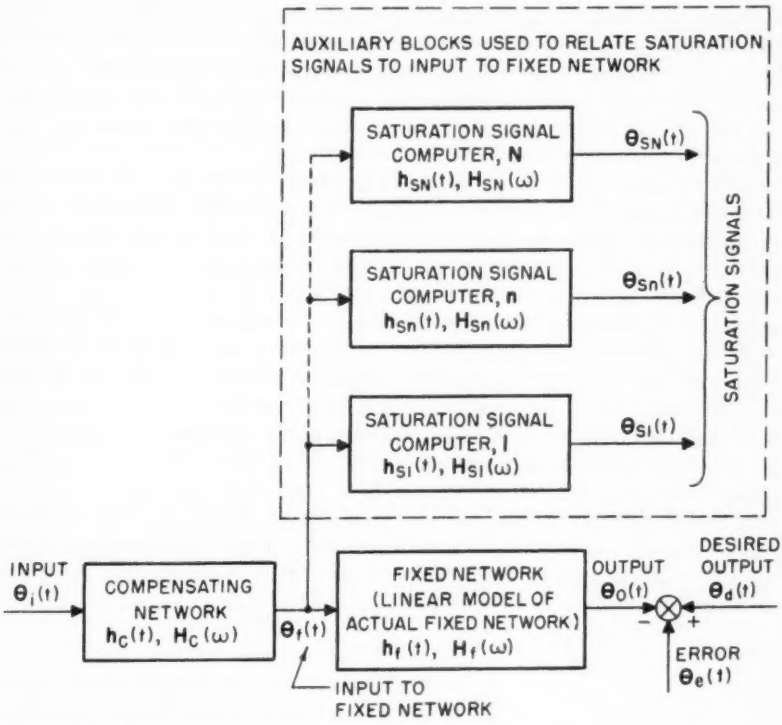

FIG. 5. Block diagram used in formulating the mathematical problem.

problems occur in which minimization of the rms. error is not the best criterion. Often for these latter, the proper criterion is either not known or is very difficult to apply, and the use of the rms. error criterion is then justified on the basis of expediency with the thought that a solution on the basis of rms. error is better than no solution at all.

As an aid in stating the mathematical problem of this paper, the block diagram of Fig. 5 is useful. In view of the equivalence of the filter and feedback-control problems pointed out in the preceding section, and

since the filter formulation is simpler than that for feedback control, this block diagram is based upon that for the filter problem, Fig. 3. The input, usually considered to be a stochastic signal, is denoted by $\theta_i(t)$. The compensating network, described completely by its impulse response $h_c(t)$ or alternatively by its system function $H_c(\omega)$, modifies the input to form the input signal to the fixed network $\theta_f(t)$. In the real system, the fixed network contains saturable elements, but in this block diagram the linear model of the actual fixed network is employed. (From now on the term "fixed network" alone will refer to the linear model of the actual fixed network.) The fixed network is thus describable in terms of an impulse response $h_f(t)$ or system function $H_f(\omega)$. By means of the fixed network, $\theta_f(t)$ is connected to the system output $\theta_o(t)$. The output is schematically shown as subtracted from the desired output $\theta_d(t)$ to form the error $\theta_e(t)$, even though the last two quantities are not actually present in the physical system but rather are conceptual in nature.

Also shown in Fig. 5 is a group of auxiliary blocks used to relate the saturation signals in the fixed network directly to the signal $\theta_f(t)$. The N saturation signals $\theta_{sn}(t)$ are the responses of those N elements in the fixed network which correspond to the N saturable elements of the actual fixed network. It facilitates the analysis to have these signals explicitly represented as functions of the N transfer relationships $h_{sn}(t)$ or $H_{sn}(\omega)$ between them and $\theta_f(t)$. To indicate these transfer relationships on the block diagram, the auxiliary blocks, called "saturation signal computers," are used. These blocks, of course, do not actually exist outside of the fixed network but are really contained inside of it.

We now state the mathematical problem to which the compensating-network design problem is reduced by means of the schemes that were outlined in Sections II and III for dealing with saturation and considering transient performance and by means of the assumption stated above. This problem will be first stated in words and then repeated in terms of symbols. In words, the problem is as follows:

Statement of the mathematical problem in words.

Given:

(1) Information about the normal input signal.
(2) Information about the relationship between the normal-input and desired-output signals.
(3) One over-all and N saturation-signal transfer characteristics for the fixed network.
(4) Limits upon the rms. values of the N saturation signals.
(5) A set of K pairs of transient-input test signals and transient-desired-output signals together with limits on the K-corresponding integral-square errors.

Find:

The transfer characteristic of the compensating network which must be cascaded with the fixed network in order to produce an over-all system such that

(1) The N saturation signals have rms. values equal to or less than the given limits.
(2) The K integral-square errors resulting from the transient tests are equal to or less than the given limits.
(3) The rms. error between the normal desired output and the system output is the minimum possible in the presence of the first two requirements.

In this statement of the problem, it must be emphasized that the transient tests are made with the normal input removed and that the rms. saturation-signal requirements are not imposed during these tests. In theory, the transient tests can always be made without saturating the system simply by using small enough amplitudes.

A restatement of the mathematical problem is now made in terms of symbols. (To do this certain results are anticipated by assigning symbols to quantities before their pertinence to the problem has been demonstrated. For example, part of the fundamental problem is to find what information concerning the normal input signal is required to determine the compensating network; this knowledge would not be available until the solution is partly worked out.) These symbols are:

$\phi_{ii}(\tau) \triangleq$ autocorrelation function of the normal input signal $\theta_i(t)$. (5)

$$\phi_{ii}(\tau) \triangleq \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} dt\, \theta_i(t)\, \theta_i(t+\tau). \tag{6}$$

$\phi_{id}(\tau) \triangleq$ cross-correlation function of the normal input signal $\theta_i(t)$ and desired output signal $\theta_d(t)$. (7)

$$\phi_{id}(\tau) \triangleq \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} dt\, \theta_i(t)\theta_d(t+\tau). \tag{8}$$

$h_f(t) \triangleq$ the over-all impulse response of the fixed network. (9)

$h_{sn}(t) \triangleq$ the impulse response of the nth saturation signal computer. (10)

$\sigma_\epsilon \triangleq$ the rms. value of the error $\theta_\epsilon(t)$ between the desired output and the system output when the system is driven by its normal input signal. (11)

$\sigma_{sn} \triangleq$ the rms. value of the nth saturation signal $\theta_{sn}(t)$. (12)

$\sigma_{smn} \triangleq$ the limit upon the rms. value σ_{sn} of the nth saturation signal. (13)

$I_{iik}(\tau) \triangleq$ *autotranslation* function of the kth transient input test signal $C_{ik}(t)$. (14)

$$I_{iik}(\tau) \triangleq \int_{-\infty}^{\infty} dt\, C_{ik}(t) C_{ik}(t + \tau). \tag{15}$$

$I_{idk}(\tau) \triangleq$ *cross-translation* function of the kth transient input signal $C_{ik}(t)$ and desired output signals $C_{dk}(t)$. (16)

$$I_{idk}(\tau) \triangleq \int_{-\infty}^{\infty} dt\, C_{ik}(t) C_{dk}(t + \tau). \tag{17}$$

$I_{ek} \triangleq$ the kth integral square of the error $C_{ek}(t)$ between the transient desired output $C_{dk}(t)$ and the transient system output $C_{ok}(t)$. (18)

$$C_{ek}(t) \triangleq C_{dk}(t) - C_{ok}(t). \tag{19}$$

$$I_{ek} \triangleq \int_{-\infty}^{\infty} dt\, C_{ek}^2(t). \tag{20}$$

$I_{emk} \triangleq$ the limit upon the kth integral-square error I_{ek}. (21)

(Note that $C_{ek}(t)$ is $\theta_e(t)$ for the kth transient test; a separate symbol is used to clearly distinguish the transient error from the normal error. Also note that the translation-function definitions restrict the class of transient test functions to those for which the defining integrals exist. This is not a severe restriction since convergence factors can be used; as an illustration see Example 3 of Section V.) In symbols the problem is as follows:

Statement of the mathematical problem in symbols.

Given:

(1) $\phi_{ii}(\tau)$.
(2) $\phi_{id}(\tau)$.
(3) $h_f(t)$ and the set of N responses $h_{sn}(t)$.
(4) The set of N limits σ_{smn}.
(5) The K sets of translation functions $I_{iik}(\tau)$ and $I_{idk}(\tau)$, and the limits I_{emk}.

Find:

The $h_c(t)$ which yields a cascaded system such that

(1) The set of N conditions $\sigma_{sn} \leqslant \sigma_{smn}$ are met.
(2) The set of K conditions $I_{em} \leqslant I_{emk}$ are met.
(3) σ_e is the minimum possible in the presence of the first two requirements.

The $h_c(t)$ which satisfies the requirements of this problem will be called the optimum compensating-network impulse response and will be denoted by $h_{co}(t)$.

The above statement of the mathematical problem is the principal result of this paper. The solution of the problem is, of course, important but not nearly so important as the idealization of the physical problem which made possible the formulation of the solvable mathematical problem. The rest of this paper gives the results which any competent engineer or mathematician could derive from the problem statement made above and the results already published in the literature.

B. A Solution in the Form of an Integral Equation

A solution for the sought-for compensating-network impulse response $h_c(t)$ can be expressed in terms of an integral equation. This equation is obtained by first formulating the normal rms. error σ_e as a function of the two impulse responses $h_c(t)$ and $h_f(t)$ and the two correlation functions $\phi_{ii}(\tau)$ and $\phi_{id}(\tau)$. In a similar way the N rms values σ_{sn} of the saturation signals are determined as functions of $h_c(t)$ and $h_f(t)$ and $\phi_{ii}(\tau)$. Next, the K-integral square errors I_{ek} are found as functions of $h_c(t)$ and $h_f(t)$ and the K pairs of translation functions $I_{iik}(\tau)$ and $I_{idk}(\tau)$. By assuming an optimum $h_c(t)$ to exist, a necessary condition which it must fulfill is found by handling the situation as an isoperimetric problem in the calculus of variations with $N + K$ constraints. This necessary condition is also sufficient and comprises an integral equation form of solution for the optimum compensating-network impulse response $h_{co}(t)$.

A statement of this solution is

$$\int_{-\infty}^{x} du h_{co}(u) \left\{ \begin{array}{l} \displaystyle\int_{-\infty}^{\infty} dy h_f(y) \int_{-\infty}^{\infty} dv h_f(v) \left[\phi_{ii}(x + y - u - v) \right. \\ \qquad \left. + \displaystyle\sum_{k=1}^{K} \rho_{ek} I_{iik}(x + y - u - v) \right] \\ \qquad + \displaystyle\sum_{n=1}^{N} \rho_{sn} \int_{-\infty}^{\infty} dy h_{sn}(y) \\ \qquad \times \displaystyle\int_{-\infty}^{\infty} dv h_{sn}(v) \phi_{ii}(x + y - u - v) \end{array} \right\}$$

$$- \int_{-\infty}^{\infty} dy h_f(y) \left[\phi_{id}(x + y) + \sum_{k=1}^{K} \rho_{ek} I_{idk}(x + y) \right]$$

$$= 0 \text{ for } x \geqslant 0. \quad (22)$$

That this can possibly form a solution for $h_{co}(t)$ can be seen if it is recognized that the $\{\}$ of the first term is merely a function of $x - u$, say $f_1(x - u)$, and the whole second term is simply a function of x, say $f_2(x)$,

so that the left-hand side is $\int_{-\infty}^{\infty} du h_{co}(u) f_1(x-u) - f_2(x)$, which is a function of x, say $f_3(x)$. Now $f_3(x)$ depends upon the shape of $h_{co}(t)$, and Eq. 22 says that this shape must be such that $f_3(x)$ is zero for x positive. (The variables x, y, u, and v are all integration variables with the dimensions of time.)

The only quantities appearing in Eq. 22 which have not been defined so far are the ρ_{sn}'s and ρ_{ck}'s. These are the Lagrangian multipliers which permit the $h_{co}(t)$ to be adjusted to meet the $N + K$ constraints on the saturation signals and integral-square transient errors. The $h_{co}(t)$ obtained from Eq. 22 is a function of these $N + K$ Lagrangian multipliers. By substituting the $h_{co}(t)$ obtained from Eq. 22 into the $N + K$ equations for the rms. values of the saturation signals and for the integral-square transient errors, it is possible to find, in theory at least, values for the Lagrangian multipliers which will allow all of the $N + K$ limit specifications, σ_{smn} and I_{emk}, to be met. For illustrations of such practical details, see the examples of Section V. Plausibility arguments for the integral equation form of solution (and also for the explicit solution given below) are presented in the appendix of this paper.

C. *An Explicit Solution Formula*

The integral equation form of the solution (Eq. 22) is rather cumbersome to use in practice. If the normal input and desired output signals are characterized by correlation functions which are Fourier transformable, and if the translation functions of transient test signals are transformable, it is possible to solve the integral equation and to obtain an explicit formula for the compensating-network system function. The Fourier transforms of the correlation functions are referred to as power-density spectra; the transforms of the impulse responses are equal to the corresponding system functions divided by 2π. The method of solving the integral equation is one of spectrum factorization first used by Wiener (4).

An explicit solution of the integral Eq. 22 is:

$$H_{co}(\omega) = \frac{L + \left[\frac{B(\omega)}{A^{-}(\omega)}\right]_{+}}{A^{+}(\omega)}. \tag{23}$$

Here

$$H_{co}(\omega) \triangleq \text{system function of the optimum compensating network,} \tag{24}$$

$$L \triangleq \text{a constant which is adjusted to yield minimum rms. error } \sigma_e, \tag{25}$$

$$A(\omega) \triangleq \bar{H}_f(\omega)H_f(\omega)\left[\Phi_{ii}(\omega) + \sum_{k=1}^{K} \rho_{ck}I_{iik}(\omega)\right] + \sum_{n=1}^{N} \rho_{sn}\bar{H}_{sn}(\omega)H_{sn}(\omega)\Phi_{ii}(\omega), \quad (26)$$

$$B(\omega) \triangleq \bar{H}_f(\omega)\left[\Phi_{id}(\omega) + \sum_{k=1}^{K} \rho_{ck}I_{idk}(\omega)\right], \quad (27)$$

$A^+(\omega) \triangleq$ factor of $A(\omega)$ which has all of the poles and zeroes of $A(\omega)$ which lie in the upper half plane, (28)

$A^-(\omega) \triangleq \dfrac{A(\omega)}{A^+(\omega)}$ and has all of the poles and zeroes of $A(\omega)$ which lie in the lower half plane, (29)

$\left[\dfrac{B(\omega)}{A^-(\omega)}\right]_+ \triangleq$ component of $\dfrac{B(\omega)}{A^-(\omega)}$ which has all of its poles in the upper half plane, and such that $\dfrac{B(\omega)}{A^-(\omega)} - \left[\dfrac{B(\omega)}{A^-(\omega)}\right]_+$ has all of its poles in the lower half plane, (30)

$H_f(\omega) \triangleq$ the system function for the fixed network, (31)

$H_{sn}(\omega) \triangleq$ the system function for the nth saturation signal computer (32)

$\Phi_{ii}(\omega) \triangleq$ the power density spectrum of the normal input signal $\theta_i(t)$, (33)

$I_{iik}(\omega) =$ the Fourier transform of $I_{iik}(\tau)$, (34)

$\Phi_{id}(\omega) =$ the cross-power density spectrum of the normal input and desired output signals, (35)

$I_{idk}(\omega) =$ the Fourier transform of $I_{idk}(\tau)$. (36)

N.B. The Fourier transform of $f(t)$, denoted by $f(\omega)$, is taken to be $\dfrac{1}{2\pi}\displaystyle\int_{-\infty}^{\infty} dt e^{-j\omega t}f(t)$ and the inverse transform as $\displaystyle\int_{-\infty}^{\infty} d\omega e^{j\omega t}f(\omega)$ throughout this paper. The system function $H(\omega)$ is related to the impulse response $h(t)$ by $H(\omega) = \displaystyle\int_{-\infty}^{\infty} dt e^{-j\omega t}h(t)$ and inversely by $h(t) = \dfrac{1}{2\pi} \times \displaystyle\int_{-\infty}^{\infty} d\omega e^{j\omega t}H(\omega)$. A bar over a quantity denotes the conjugate; thus $\bar{H}_f(\omega)$ is the conjugate of $H_f(\omega)$.

In using Eq. 23, $\left[\frac{B(\omega)}{A^{-}(\omega)}\right]_{+}$ is frequently not obtainable by the partial fraction expansion method. In this event an auxiliary equation for this quantity can be used, *viz.*:

$$\left[\frac{B(\omega)}{A^{-}(\omega)}\right]_{+} = \frac{1}{2\pi}\int_{0}^{\infty} dt e^{-j\omega t}\int_{-\infty}^{\infty} dw e^{jwt}\frac{B(w)}{A^{-}(w)}. \tag{37}$$

The constant L in Eq. 23 is determined by finding the value which produces a minimum rms. error. The Lagrangian multipliers, ρ_{sn} and ρ_{ck}, in Eq. 23 are determined by the same procedure as described in connection with the integral equation of the preceding subsection.

To be continued.

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BIO-MECHANICS, A NEW APPROACH TO MUSIC EDUCATION

BY

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INTRODUCTION

This paper is concerned with a new approach to musical skill training. Consequently, we shall deal with two different problems:

1. The statement of a research program for musical performance and the necessity of having this program established.
2. The presentation of new research tools. They are considered to be instrumental for the successful achievement of the proposed program.

Thus it will be proposed to develop in musical skill training the kinesthetic sense to a much greater extent as compared to present practice and, at the same time, learn to depend to a lesser degree on the guiding function of ear and eye. This could be achieved by introducing principles of bio-mechanics into musical training.

It must be emphasized that insofar as the present paper concerns itself with actual use of and measurements with the instruments described, the purpose is not, at the present time, to give experimental results in finished form and discuss their significance, but rather to describe and illustrate the experimental methods which are proposed in the hope that they will be of service to others.

A scientific movement in music education in the United States started in the last decade of the 19th century, and it is characterized by testing and measuring of musical talent. It was the psychologist and not the musician who started it. It is a known fact that music educators have, thus far, stayed away from the scientific study of music education, and that they are only barely acquainted with scientific music literature. Instinct, or feeling, is still their supreme guide, which keeps them from occupying themselves with the rational fundamentals of musical skill. As a consequence, our present methods of teaching musical instruments, voice, and conducting depend largely upon arbitrary authority. The lack of rational fundamentals of theory and practice of musical performance, caused through the absence of a scientifically based methodology, is the cause of a very serious inefficiency of training methods in music education. This results, for the average music student, in an excessively long training time and a poor musical skill.

The psychologist, not hampered by musical tradition, could easily establish himself in research of music education. In the United States,

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under the leadership of C. E. Seashore, a scientific movement evolved, called "Psychology of Music," which has occupied for a long time a leading position in research of music education. Description and explanation in musical skill has to draw from several sciences, such as history and theory of musical practice, physics, mathematics, physiology, anatomy, and anthropology. "Psychology of Music" (**1, 2**)[2] had to limit itself to those topics amenable to treatment in the psychological laboratory, by omitting such important disciplines as physiology and anatomy. It thus became selective rather than systematic. Its main objective became measuring of musical talent, and its great limitation was summed up by Dykema and Gehrkens (**3**): "Measurements of skill indicate potentiality but do not guarantee that the powers will be adequately used."

In order to surpass existing musical training methods we need objective criteria for the development of new methods. We may find these criteria in the "scientific method" which demands the consideration of all the factors affecting a given situation. Consequently, we will turn our attention to some of the disciplines hitherto neglected by the psychologists, namely, physiology, anatomy, physics, and mathematics.

During the past years there has been a trend among music teachers to lean toward the scientific approach. Various teaching methods appeared which claimed to have a scientific basis. But with few exceptions, most of what has been written about it is no more than a rationalization of arbitrary authority. Let us take, as an example, the concept "naturalness" which has been so often used as a yardstick for superiority of a certain method. Certain violin schools consider the "Russian" bowing method as the one which alone can meet "naturalness." Whereupon we may ask: what are the criteria for measuring the degree of achieving it, and how is this concept in itself being defined?

We may summarize the objectives of a new scientific approach to music education as follows:

1. To improve musical skill and quality, and thus, to raise the average musical skill level.
2. To provide insight into all significant factors which determine acquisition and mastery of skill.
3. To shorten the training time. This is particularly important for the study of string instruments.
4. To establish anatomical-physiological playing methods which will prevent excessive strain, and thus, occupational diseases. This may also contribute to a better insight into the cause, prevention, and treatment of professional diseases of the musician.
5. To increase number and skill of amateur musicians, which in turn may increase the interest in the art of music.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

CRITERIA FOR MUSICAL TONE PRODUCTION

Helmholtz (4) developed physical-acoustic definitions for a "correct" tone produced on a violin which corresponds to the musical-aesthetic concept of a beautiful tone. He found that the violin will only produce a pure, uninterrupted tone if the bowing will be kept steady, uninterrupted, and with an optimal amount of friction between bow-hairs and strings. He proved the dependence of the sound-vibrations from the bow motions. Tonal quality is determined by a proper relation between fundamental and partial tones, as well as the presence and strength of both. A full tone results only when the prime tone is distinct. Helmholtz (4), Krigar-Menzel, Raps, Steinhausen (5), Swann (6), Saunders (7), and Abbott (8) have established that the full, large tone of a bow instrument depends on a relatively high bow velocity and a relatively low bow pressure. The basic problem of bowing a violin is how to meet these physical acoustic requirements of the instrument.

It was Friedrich Steinhausen (5) who first, to the best of our knowledge, had investigated a fundamental physiological approach to this problem. He also studied the principles of piano technique from an analogous viewpoint. He established a basic principle for bowing in violin playing by stating that correct tone production requires physiologically correct arm motion forms, with bowing being essentially a mechanical-physiological problem. However, he restricted his investigations to the bow arm up to the shoulder of this arm, and not beyond.

The author's experience has shown that it is insufficient to look at bowing as a mechanical-physiological problem of the bowing arm only. The needs of a highly perfected violin technique require that bio-mechanical functions of the entire body be included. The older concept of the *arm* performing the bowing is being replaced now by the concept of the *body* performing this function. It seems to us more useful not to think any more in terms of a "right" and "left" hand technique, but rather of an "entire body" technique. This concept will be explained in more detail in the subsequent sections.

BIO-MECHANICS—ITS ASPECTS FOR MUSIC EDUCATION

Bio-mechanics is concerned with the mechanics of the body, that is, with statics, or posture; with kinematics, for example of arm motions, considering only concepts of geometry and time; and with dynamics, dealing with the effect of unbalanced external forces, or of muscle forces, in modifying the motion of bodies, for example, limbs. All concepts of general mechanics are included, such as inertia, momentum, Newton's law of action equal to reaction, with all being applied to the living body.

For the purpose of musical performance and teaching, and for the investigation of new methods pertaining to both, the author found it expedient to subdivide the bio-mechanical concept into two main divisions:

1. *Analytical Bio-mechanics* is observant; its purpose is the analysis of motions and forces as a means of interpretation and evaluation of musical performance methods.

2. *Synthetical Bio-mechanics* is creative; its purpose is the construction or composition of body motions, based on analytical findings, with the purpose of creating optimal bio-mechanical conditions.

To the author's knowledge, only the analytical approach has, so far, been extensively utilized. The synthetical one, however, has found its practical application mainly in the sports where optimal motion forms, as well as coordinations, have been devised—for instance the "follow-through" principles—and in dancing. Another field of application has been the rehabilitation of amputees and other disabled.

The basic concepts of synthetical bio-mechanics have already been announced by German physiologists. O. Fischer (9) has interpreted the body as a kinematic chain which consists of six different parts: foot, shank, thigh, trunk, upper arm, and forearm with hand. If one end part, such as the foot, has a definite position in space, every other link of the chain has a predetermined form of motion which is determined by its connection with the other link, according to du Bois-Reymond (9). The limitations imposed upon the range of motion of each link express this condition. Most types of bodily work consist of having the feet as fixed links of the system, from which the hands are being moved, and thus, are performing the work. Du Bois-Reymond summarizes (9):

1. A motion made by one part of the body can be achieved by a variety of motions of the other parts.

2. In the case of the selection of a proper motion form, muscle groups which have apparently no influence on the moved extremities can be brought into play.

3. The selection of proper motion forms occurs generally through subconscious coordination, but often the use of auxiliary muscles has to be learned.

4. It is not only habit derived from practice and experience which prefers certain motion forms by excluding others, but efficient coordination can be, so to speak, mechanically forced by creating pathways in the central nervous system.

We may thus conclude that bowing of the violin involves the bowing hand, bowing arm, and the rest of the kinematic chain down to the feet.

Analytical bio-mechanics in music research is, for instance, represented by the use of cyclogrammetry which will be discussed in a later section.

WORKING HYPOTHESIS OF BODY-MOBILITY AND ITS APPLICATION TO VIOLIN-PLAYING

Results gained from tests and from teaching others, and comparing them with the investigations made by Steinhausen, Helmholtz, and

others, have led the author to formulate new concepts of musical skill. These hypotheses need further investigations to verify their general validity. A representative number of test subjects will be required. These tentative concepts, as shown in their application to violin playing, may be applied to any other musical instrument if properly adjusted to the specific task; this would include any complex skill outside of musical skill.

The presentation of a hypothesis of body mobility has as its purpose the pointing out of specific objectives which our research will have to explore.

For the purpose of illustration, we shall now describe one of the

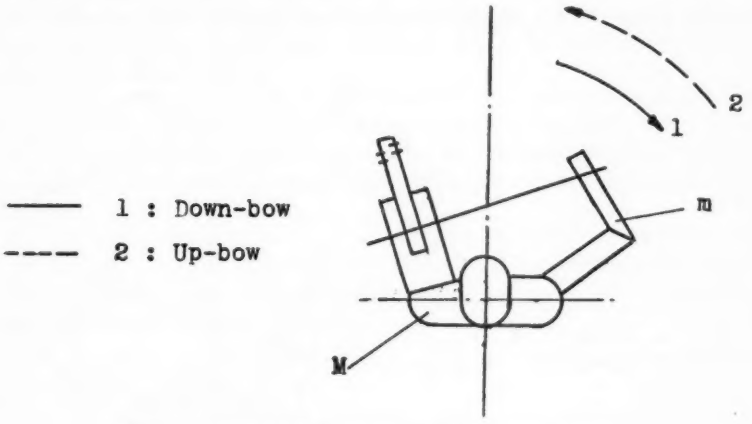

FIG. 1. Scheme showing the concept of unilateral bowing.

hypotheses in more detail. For this reason, we shall introduce new concepts of bowing:

1. *Unilateral bowing* is the method in which mainly the bowing arm *m* is used, whereby the rest of the body *M* including the violin is kept rather quiet. Figure 1 shows the diagram of this method.

2. *Bilateral bowing* is the method in which the rest of the body *M* participates in the bowing motion, with bowing arm *m* continuously moving in opposite direction of body part *M*. This type of motion actually amounts to *dynamic balance* of parts *m* and *M*. Figure 2 shows the diagram of this method.

Our hypothesis claims that bilateral is superior to unilateral bowing. Extensive experience has shown that unilateral bowing causes higher muscle tension in the bow arm, and thus, stiffness of bowing and excessive bow pressure. It also causes similar reactions in the *left hand*. Unilateral bowing exerts kinetic loads on various muscle groups throughout the body; the center of gravity of the body is forced to shift con-

tinuously and additional static muscle work is required to maintain static body balance. However, according to Atzler (9), static muscle work disturbs the coordination of motions.

On the other hand, it is assumed that bilateral bowing will produce minimal static muscle work and minimal muscle tensions in both arms, hands and fingers. It is also maintained that bilateral produces a much higher tone quality and greater skill of bowing as compared to unilateral bowing.

By no means is it for bowing alone that bilateral is superior to unilateral motion. Experience has shown that there are also other bilateral motions required to round out the total, harmonious body motion.

There are, however, still other important factors which enter the picture when we are aiming at the most perfect of all possible body

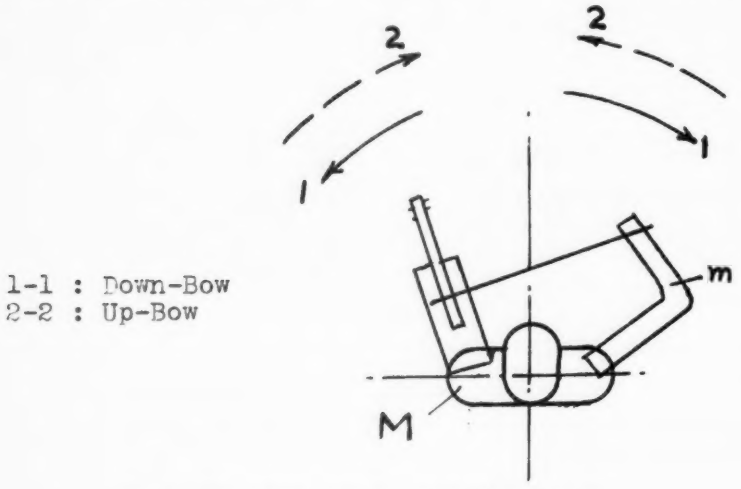

FIG. 2. Scheme showing the concept of bilateral bowing.

motions: the total harmonious body motion. These additional factors are: (*a*) stance and posture; (*b*) terminal grip and finger positions; (*c*) interrelation between bilateral motions, stance and posture, and terminal grip and finger positions (that is, a wrong grip, wrong stance and posture will interfere with the free execution of bilateral motions, or vice versa, unilateral motion exerts additional muscle strain on grip, stance and posture); and (*d*) interrelation of the shape and design of the "tool," such as the violin bow, to the bio-mechanical function. Steinhausen had pointed out that the present shape of the bow is a perfect adaptation of a tool to bio-mechanical function.

It is expedient for our purpose to line up our various hypotheses in order, starting with the one which we believe to be dominant:

1. A relatively higher degree of body mobility, with regard to all parts of the body, increases skill and work efficiency; a lower degree of mobility decreases skill and work efficiency. There exists an *optimum of body mobility.*

2. Utilization of the principle of dynamic balance will result in an increase of skill and efficiency, and a decrease in muscle tension and fatigue throughout the body. The principle of dynamic balance leads to the design of bilateral motion forms.

3. For each type of work there exist an optimal stance and an optimal distance of the feet. For violin playing it is the close to parallel position of the feet. Wrong stance interferes with free body mobility and good posture.

4. Posture—that is, proper alignment of legs, trunk, and head—if wrong, will interfere with body mobility, and will itself depend to a certain degree upon stance.

5. Terminal grip and finger positions on bow and violin should be conceived in a "dynamic" sense rather than in a "static" one. Both must conform to anatomical-physiological requirements, and to optimal bio-mechanical events; if incorrect, they will hamper free body mobility. "Dynamic" grip is a flexible grip.

6. The dynamic grip must be so devised that the instrument will become a physiological extension of the body. Conversely, the design of the instrument (bow, violin) must be such that it can become easily a physiological extension of the body.

To contribute to a better understanding of these principles, a few details will be discussed:

(*a*) An important compensatory, bilateral motion for shifting the strings consists of moving left shoulder, arm and violin always opposite to the respective bow motions.

(*b*) Hips move in the same direction as the bow arm does.

(*c*) Excessive muscle tension in one hand stiffens the other hand simultaneously.

(*d*) Posture should be erect. Bending forward of the trunk causes lifting of the right upper arm which, in turn, decreases the natural arm weight bearing down upon the bow. This requires an undesirable increased muscle tension in the right hand to maintain sufficient bow pressure.

(*e*) From the viewpoint of full body mobility in violin playing, standing is preferable to sitting. When being seated however, conditions should be made such as to approach those of the standing position. The feet should be parallel and close to each other. Shanks should be close to perpendicular. One should sit close to the edge of the chair, not toward the back and by no means lean against the same. The seat should be horizontal and not be made of too soft a material.

(*f*) The bow, as well as the violin at the chin, have to be held "dynamically"—flexibly, that is—and must follow the total of body motions. This dispenses with using any type of cushion. A cushion is undesirable both acoustically and bio-mechanically. The dynamic grip of both bow and violin is the premise for both becoming physiological extensions of the body.

PROJECT OBJECTIVES

So far, evaluation and teaching in musical performance have been chiefly based upon the control exerted by the human ear. This, however, has at least two basic drawbacks:

(*a*) The acuteness of the human ear varies significantly among musicians and is therefore an unreliable yardstick for quality of tone production. It is equally unreliable to evaluate musical skill and efficiency of musical training.

(*b*) No musical performer, while playing (or singing), can hear himself accurately. Thus, the ear, as a judge, when listening to oneself is inferior compared to when listening to others. This necessitates depending on the acuteness of the hearing of others which, as stated above, is unreliable.

Investigation and formulation of motion theories of musical skill, and a unified methodology for musical performance call for reliable evaluation and measuring methods. This suggests an approach in two successive steps:

1. Development of a compound, objective measuring technique with a minimum of human error involved, for the evaluation of tone quality, skill and efficiency in musical performance.
2. Utilization of this measuring technique for the development of optimal performance techniques through systematic comparison of various methods of performance, together with a detailed study of all pertinent factors which determine the total method. Thus, it may be expected to use the results of music research as contributing factors for a general science of human skill.

In the teaching of musical skill, objective measuring techniques offer (*a*) to diagnose concisely skill and efficiency of students; (*b*) to control and direct more accurately musical training; and (*c*) to predict the results of musical training.

NEW RESEARCH METHODS

Without going into all the steps which would be required in such a proposed research program, a few measuring techniques which have been developed or used for our particular purpose for the first time, or are proposed for future research, will be discussed.

1. *Sound Spectrograph*

The writer, with the kind assistance of Dr. F. S. Cooper of Haskins Laboratories, New York, N. Y., has investigated the applicability of the sound spectrograph to bio-mechanical analysis in instrumental playing. The sound spectrograph can be utilized to record for visual study the differences in tonal results which are achieved by applying different methods of playing, involving different motion patterns, stances, postures, etc. The sound spectrograms, Figs. 3, 3*a*, 4, and 4*a*, show each tone represented by a number of parallel horizontal lines, representing

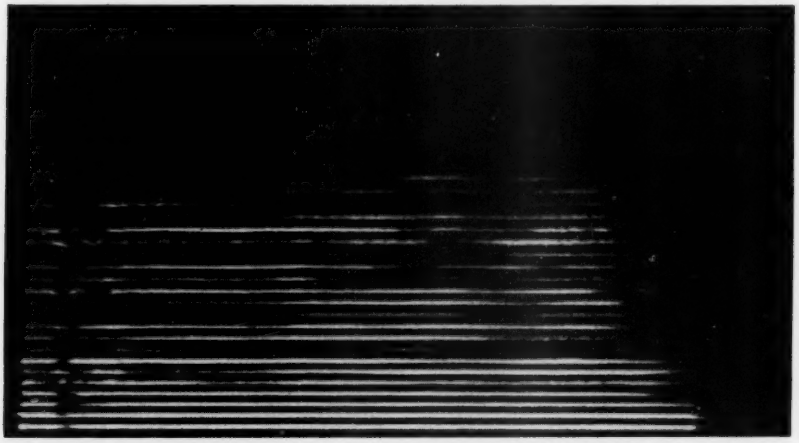

FIG. 3. Sound-spectrogram of open G string, one full bow length, unilateral bowing.

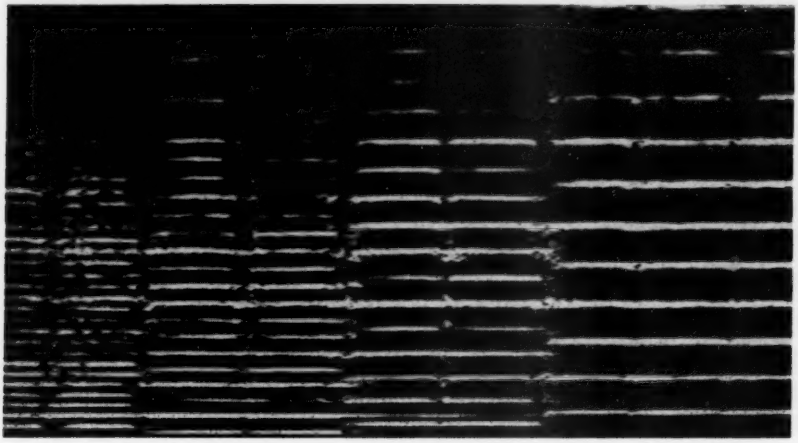

FIG. 3*a*. Sound-spectrogram of open G, D, A, E strings, short down and up strokes, unilateral bowing.

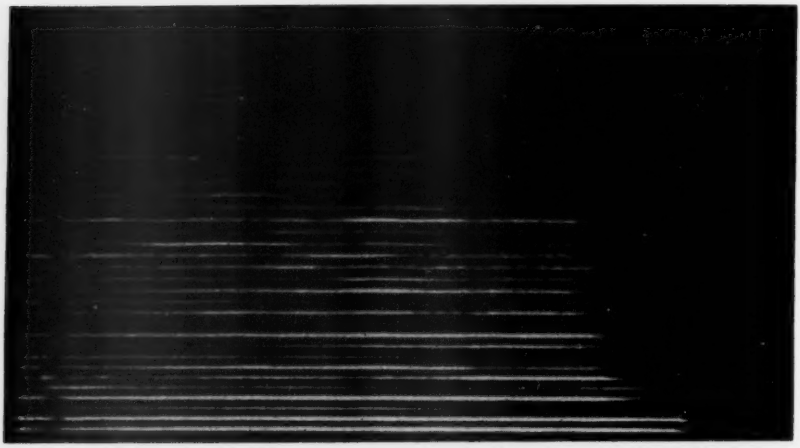

FIG. 4. Sound-spectrogram of open G string, one full bow length, bilateral bowing.

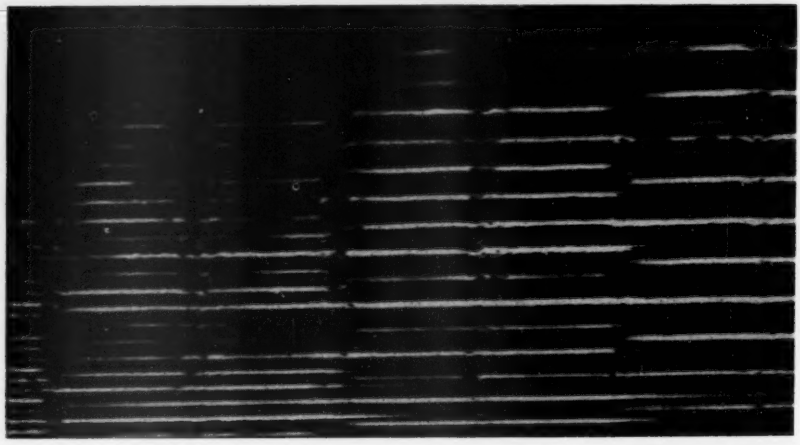

FIG. 4*a*. Sound-spectrogram of open G, D, A, E strings, short down and up strokes, bilateral bowing.

the fundamental and its upper harmonics. These spectrograms differ from earlier graphical representation of acoustic spectra such, for example, as were used by Seashore and his associates to portray the harmonic structure of steady state tones and chords. Our spectrogram shows the variations with time of the harmonic composition of successive tones. That is, it presents the dynamics of the tones and thus portrays both harmony and melody.

The spectrograph, as a research instrument, was developed originally at the Bell Telephone Laboratories. However, Figs. 3, 3*a*, 4, and 4*a*

were analyzed with the special-purpose sound spectrograph at Haskins Laboratories, New York. This instrument is similar in operating principles, Fig. 5, to the Bell Laboratories spectrograph but produces film transparencies with the relative intensities of component tones accurately represented over a rather wide dynamic range, ca. 40 db. Briefly, the spectrogram is recorded by the repetitive analysis of a short sample of sound recorded on a loop of magnetic tape. The pass band of the variable filter is scanned slowly through the total frequency range of about 7000 cycles per second while the recording light moves across the width of a loop of photographic film. Magnetic tape and film loop move in unison so that time relationships on film and tape are maintained. The recording of a complete spectrogram requires approxi-

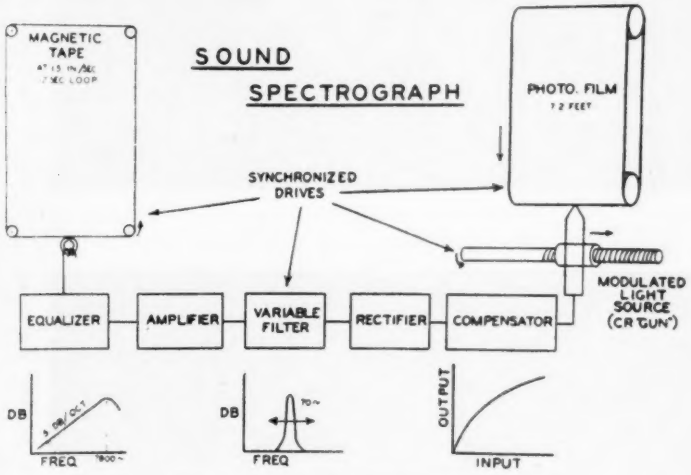

FIG. 5. Scheme of sound spectrograph.

mately an hour and twenty minutes; however, the process is almost entirely automatic.

In our spectrogram, the photographic density of the parallel lines indicates the intensity of tone at a particular instant of time. The frequency is indicated by the vertical distance from the base line (1200 cycles per inch), and time progresses from left to right along the base line (7.2 in. per second). Thus, the single picture shows all the important information about basic acoustic characteristics, that is frequency, intensity, and variations with time, or in musical terms, pitch, loudness, and melodic pattern. Quality, or timbre can also be seen. In a pure tone, all lines are fully and strongly developed, with no splotches, or spots, between the lines. The clearest picture means the clearest tone. A tone of deficient quality shows parallel lines which are weakened in

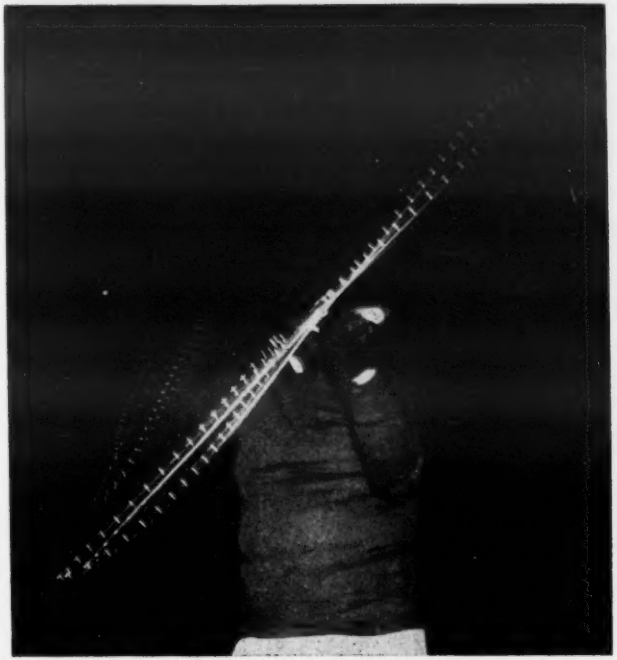

FIG. 6. Sample stick picture (using Scotch-lite tape) for cyclogrammetry; unilateral bowing.

FIG. 7. Sample stick picture (using Scotch-lite tape) for cyclogrammetry; bilateral bowing.

spots, partially or completely blotted out, with splotches or spots between the lines. The splotches in the picture represent undesirable noise caused by a deficient playing technique.

Figures 3, 3*a* show the tonal results of unilateral bowing, and Figs. 4, 4*a* those of bilateral bowing. In this way, the difference of the two methods can be established purely visually and without the aid of the human ear.

2. *Cyclogrammetry*

Work studies based on bio-mechanical analysis and using chronocyclograms have been extensively performed in different European countries. The Russian work physiology school has made a special contribution to the development of cyclogrammetry with the names of N. Bernstein (**15, 16**), Kektschejew and T. Popowa to be mentioned. Bernstein has introduced mathematical analysis into chronocyclography. He and Popowa applied this method to the analysis of the bio-dynamics of piano touch and motion forms in piano playing (**10**). R. Drillis (**11–14**) of Latvia has introduced an important refinement, the gliding cyclograph. This is a movie camera with the film moving at uniform speed. Thus, an overlapping of the photographed pictures is avoided and bio-mechanical analysis is improved and less time-consuming. He applied his method for the analysis of flax swinging, filing, nail driving and sewing.

We may use cyclogrammetry for the analysis of all body motions involved in musical skill. In order to explore the applicability of this measuring technique to our research program, we have taken a simple example, the bowing motion in violin playing, and have tried to study differences between unilateral and bilateral bowing. In order to study the changes in bowing skill, which are equivalent to changes in tone quality, and which we assume to be caused by varying body motion patterns, photographic recordings are made of the bowing motions of the subject. Figures 6 and 7 show the resulting photographic records which are called the chronocyclograms. Their analysis gives us graphical curves of velocities and accelerations of various points on the bow, violin, arm and body, which are plotted relative to time. These curves, pertaining to the motions of the tip of the bow, are shown in Figs. 9 to 12.

Interrupter Camera

In order to obtain the chronocyclograms we used an interrupted-light camera. This type of equipment represents a joint development of the Prosthetic Devices Study, Research Division, College of Engineering, New York University and the Prosthetic Testing and Development Laboratory (PTDL), Veterans Administration, New York. It has been completely described by A. Nathan and B. Walder (**17**). A

brief description of the camera designed and built by the PTDL as shown in Fig. 8, is presented herein. It consists of a 5 × 7-in. view camera with specially constructed backs and a slotted disc that rotates in front of the lens. The camera backs are adjusted so that no focusing is necessary for the different pictures taken. The slotted disc is driven at a speed of 1200 rpm. by a synchronous motor. The angle of the slot is such that the exposure time is approximately 1/500 second.

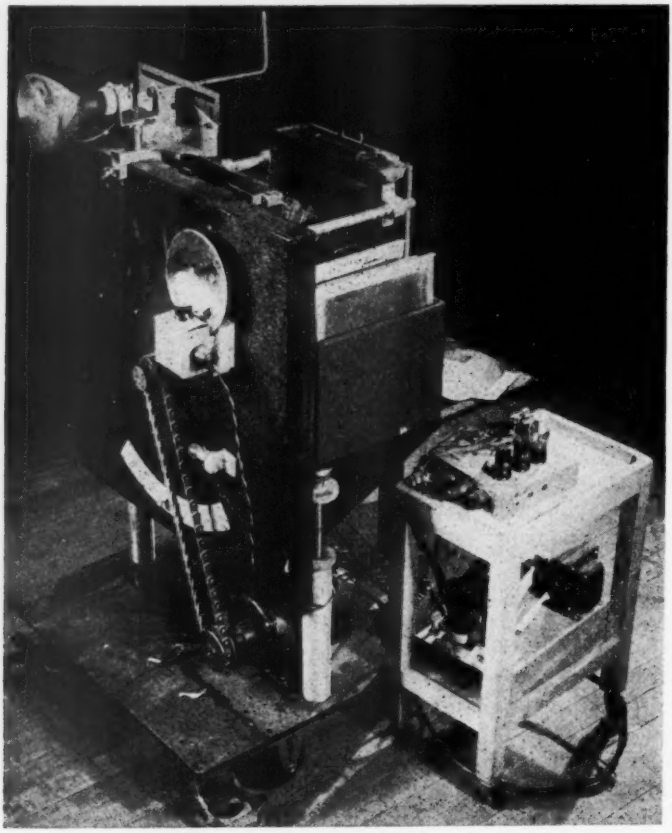

FIG. 8. Interrupter camera, for taking stick pictures.

For marking the points under study, highly reflective "Scotch-lite" tape, which acts as a brilliant target for the camera, was used. The repetitive photographs show up as stick diagrams precisely spaced in time, Figs. 6 and 7.

The European work physiologists have attached small light bulbs (connected to wiring) to the various joints of the extremities. This

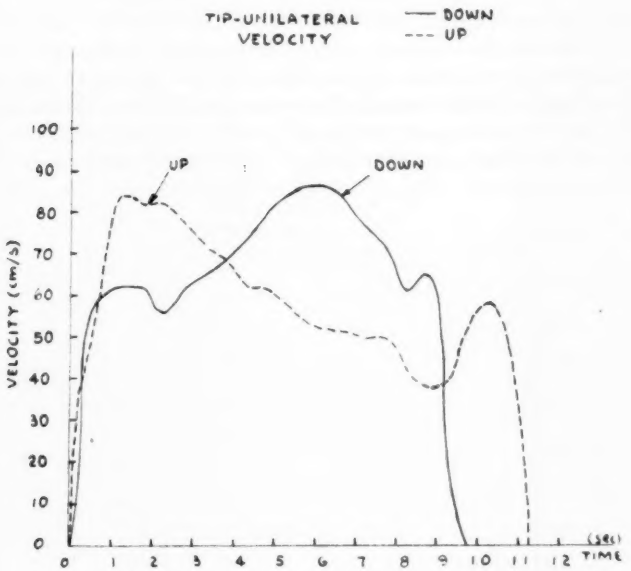

FIG. 9. Velocity curves of the tip of the bow, unilateral bowing.

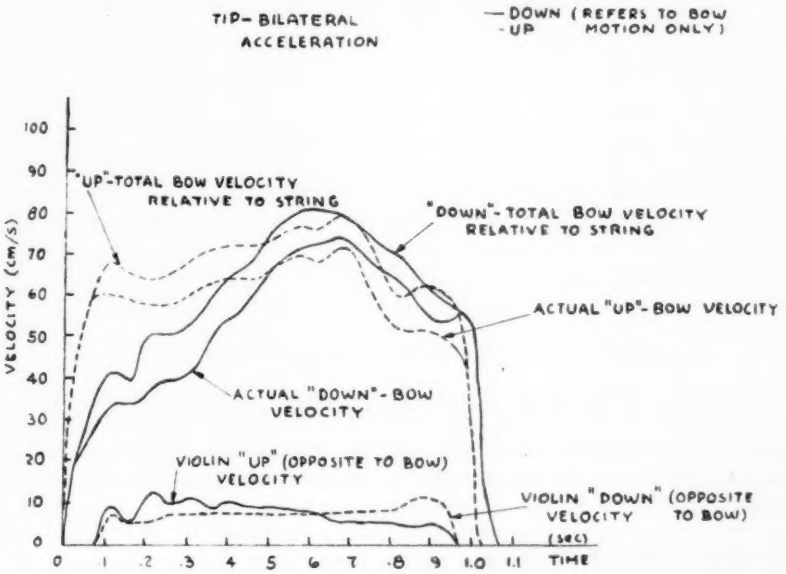

FIG. 10. Velocity curves of the tip of the bow, bilateral bowing.

constitutes in our opinion an element of interference with the free motions of the subject under test. "Scotch-lite" tape, on the other hand, consists only of small strips which can be pasted to any part of the body without causing any interference with the motions and is therefore a distinct improvement compared to the method which uses light bulbs and wires attached to the body. As above described, scotch lite

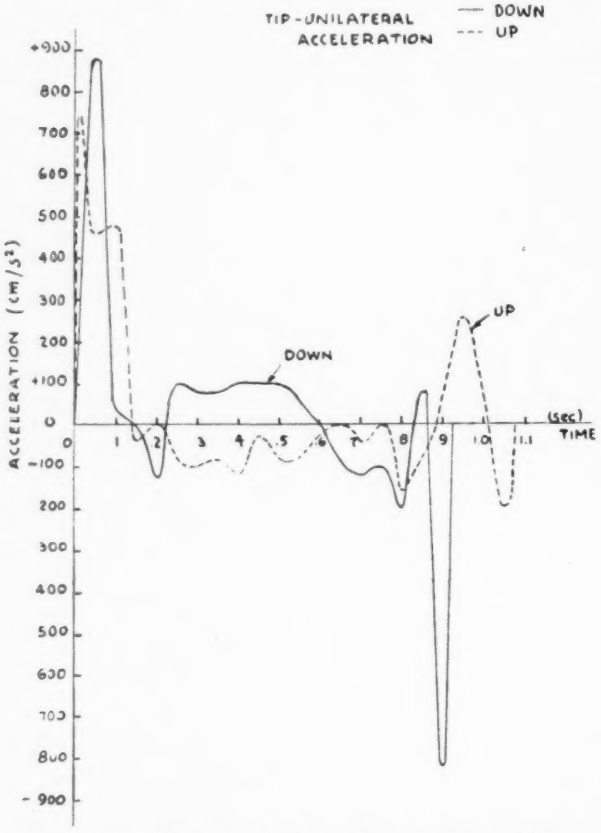

FIG. 11. Acceleration curves of the tip of the bow, unilateral bowing.

has been successfully used for testing of artificial legs. The author has introduced its use for the purpose of the proposed research program in musical skill.

Measuring Technique

Cyclogrammetry, when used for research in musical skill, should be applied for the analysis and evaluation of the various motion structures (patterns) in terms of time, velocity, and acceleration, and the

results should be correlated with the tonal qualities which we have recorded through the sound spectrograms. This approach will give us a much deeper insight into the interrelation between motion structures and tonal qualities than any existing methods for evaluating musical skill could possibly render.

Throughout the described tests the author acted as the subject. He played with a black hood on his head, with black gloves and shirt

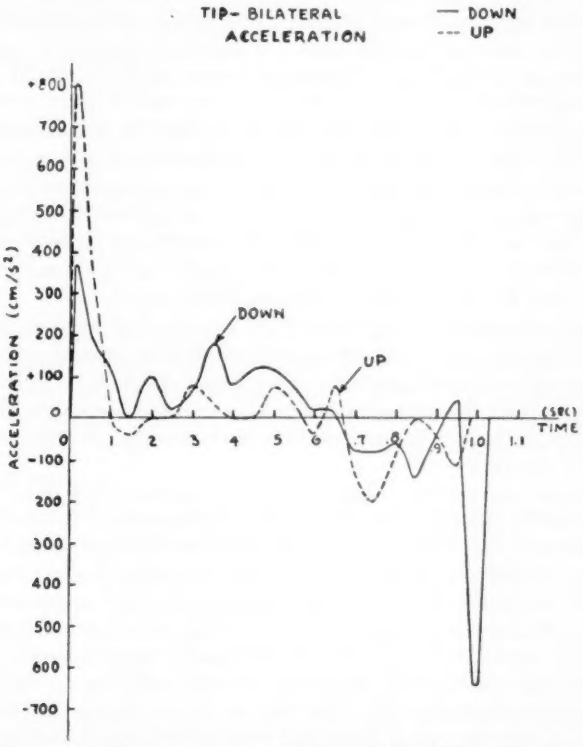

FIG. 12. Acceleration curves of the tip of the bow, bilateral bowing.

so as to allow the scotch lite to be distinctly photographed. Scotch lite was attached to both tip and frog of the bow so as to obtain an indicator of the amount of spacial error resulting from the fact that the photographs were only taken in one plane. In order to obtain a truly spacial picture of the motions, a mirror on top of the subject, under 45 degrees inclined, should be used while the photographs are being taken. Scotch lite was also attached to the scroll of the violin for a closer analysis of bilateral bowing, Fig. 7, and finally to wrist and elbow of the bowing arm.

Figures 9 to 12 show the resulting graphical curves of velocities and

accelerations of the tip of the bow, for unilateral and bilateral bowing, respectively. We must point out, however, that these curves could not be considered as a conclusive proof that bilateral is superior to unilateral bowing motion. Due to spacial distortions the errors were up to 14 per cent. Only one bowing cycle, performed by one subject, was recorded. In order to make the results statistically significant, we should need a series of cycles (recorded by a gliding cyclograph) and a number of subjects.

The glove and hood used proved to be external factors which interfered with the normal bowing skill. The glove disturbed particularly at the reversals of the bow. Darkened hands and face would eliminate these interferences.

The resulting curves may for these reasons be only considered as indicators of what information may be expected from the use of chronocyclograms for bio-mechanical analysis in instrumental playing.

Bowing was performed on the open A string, with the rate of one full stroke per second. A metronome was used and part of the task in this test called for maintaining the bow velocity uniform and for keeping the times used for down- and up-stroke about equal.

We were interested to learn which of the two bowing methods would approach closer the objective criteria for musical tone quality of bowing, namely, uniformity and relatively high bow velocity. We also wanted information about the accelerations taking place in both methods, which would be an indicator of the smoothness of bowing, particularly at the reversals of the bow.

Looking at the curves, Figs. 9 to 12, it appears that the times used for down- and up-stroke are more nearly identical in bilateral bowing than in unilateral bowing. Figure 10, bilateral bowing, shows the influence of the opposite moving violin on the resulting "total bow velocity relative to the string" which actually determines the tone quality. The total bow velocity curves relative to the string were obtained by adding the absolute velocity curves of both bow and string, respectively. According to these curves, the total bow velocity relative to the string for up-bow for bilateral, Fig. 10, looks much more uniform than the corresponding one for unilateral bowing, Fig. 9. The acceleration curves, Figs. 11 and 12, also indicate certain differences between the two bowing methods. But as has been said before, no conclusion about the superiority of either of the two bowing methods could be drawn from the present results.

3. Musical Judges (Scoring Method)

Recordings of the live tone will have to be used in order to qualify and interpret the sound spectrograms. For this reason we may use a group of competent musical judges whose ratings will be scored and statistically analyzed.

4. Physiological Studies

Studies regarding muscular and postural changes during instrumental playing warrant further investigation by Electro-Myography. Recordings of muscle potentials should be obtained from the contracted muscles of both lower extremities and of the dynamic muscle groups of the shoulder girdle and arms. Analysis of data obtained in such a study will be indicative of differences in muscular effort between various methods of playing.

5. Psychological Studies

It is reasonable to assume that there may exist a correlation between bio-mechanical and psychological factors in instrumental playing. As an example, excessive muscle strain may produce disturbances in sight reading and/or memory, or may produce anxiety while playing. For these reasons, the inclusion of the study of certain psychological phenomena pertaining to musical performance may be indicated in this program.

SUMMARY

We may state our opinion that bio-mechanics forms the rational fundamentals of musical skill. Without mastery of these fundamentals, the way to that intangible cannot be fully opened which constitutes the essence of artistry.

Acknowledgment

The author wishes to express his indebtedness and acknowledge the gracious assistance tendered him in the execution of developing new test methods by: Mr. Renato Contini, Research Coordinator, and Dr. Sydney Fishman, Ass't Proj. Director, Research Division, College of Engineering, New York University, New York; Mr. Anthony Staros, Chief, PTDL, Central Office, Vet. Admin., New York; Dr. Frank Cooper, Director of Haskins Laboratories, New York, N. Y. He is finally most grateful to the advice Dr. W. F. G. Swann, Director of the Bartol Research Foundation, Swarthmore, Pa., has given.

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ON THE INVARIANTS IN THE TURBULENCE IN COMPRESSIBLE VISCOUS FLUIDS *

BY

M. Z. E. KRZYWOBLOCKI [1]

SUMMARY

Loitsianskij (2)[2] derived the invariant disturbance moment in a homogeneous, isotropic turbulent flow of an incompressible, viscous fluid. In the present note the author derives some moments in a homogeneous, isotropic turbulent flow of a compressible viscous fluid.

1. BASIC EQUATIONS AND NOTIONS

In (1) the author derived the fundamental "generalized" equations for the propagation of the velocity and temperature correlation functions in a homogeneous, isotropic turbulent flow of a compressible, viscous fluid. After some elementary transformations they have the form:

$$(\overline{\eta f})_{,t} + 2[(\overline{\eta h})_{,r} + 4r^{-1}(\overline{\eta h})] = (\overline{\beta f})_{,rr} + 4r^{-1}(\overline{\beta f})_{,r} - \overline{\beta_{,r} f} - 4r^{-1}\overline{\beta f} + 2r^{-3}\int r^2 m dr - m + F_1, \quad (1.1)$$

$$F_1 = 2\overline{\beta N} - \tfrac{1}{3}(r\overline{\beta N})_{,r} - r\overline{\beta_{,r} N} - 2K^{(2)}, \quad (1.1a)$$

$$J[(\overline{c_p c'_p \theta})_{,t} - \tfrac{1}{3}r\overline{u^{-2}\eta^{-1}K^{(3)}(c_p c'_p \theta)_{,r}}] - R^{-1}\overline{\eta^{-1}(c_p p p'_{,t} + c'_p p' p_{,t})} - \tfrac{1}{3}rR^{-1}\overline{u^{-2}\eta^{-2}K^{(3)}(c'_p p_{,r} p' + c_p p'_{,r} p)} = J\overline{\eta^{-1}[(\gamma\theta_{,r})_{,r} + 2r^{-1}\gamma\theta_{,r}]} + W, \quad (1.2)$$

$$\gamma = \overline{\rho c_p k'} + \overline{\rho' c'_p k}, \quad W = -5\overline{\lambda[3f_{,rr}(0) + N(0)]}, \quad (1.2a)$$

where the subscripts with a comma denote partial differentiation and the symbols have the following meaning:

$$\eta = \overline{\rho\rho'}, \quad \beta = \overline{\mu\rho'} + \overline{\mu'\rho}, \quad m = \overline{p\rho'_{,t}} + \overline{p'\rho_{,t}},$$
$$N = \overline{\eta^{-1}(r^{-1}\eta_{,r} f + L)}, \quad L = r^{-3}\int \overline{\rho_{,t}\rho'_{,t}} r^2 dr,$$
$$K^{(2)} = \overline{(\rho\rho')_{,t} u^2}, \quad \theta = \overline{TT'}, \quad K^{(3)} = 3r^{-3}\int r^2 K^{(2)} dr,$$
$$\lambda = \overline{\eta^{-1}(\mu\rho' c'_p T' + \mu'\rho c_p T)}.$$

* Presented before the 1952 Heat Transfer and Fluid Mechanics Institute, University of California, Los Angeles, Calif.

[1] Fluid Dynamics Panel, University of Illinois, Urbana, Ill.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

The functions f and h correspond to the Friedmann-Loitsianskij association moments. Multiply continuity equation at the point P, written in the form $\rho_{,t} + (\rho u_i)_{,i} = 0$ by $\rho' Q^2$ and that at the point P' in the form $\rho'_{,t} + (\rho' u'_k)_{,k'} = 0$ by ρQ^2. The symbol Q denotes any turbulent quantity like u, ρ, p, T, etc. Consequently, $\overline{Q^2}$ is independent of r and depends upon t only.

Add the two continuity equations as modified above and apply the averaging process. Denoting the linear form $\overline{\rho\rho' Q^2 u_i}$ by the symbol $w_1\xi_i$, where $\vec{\xi} = \overrightarrow{PP'}$, and the linear form $\overline{\rho\rho' Q^2 u'_k}$ by $w_2\xi_k$ and using the elementary formulas for differentiation of tensor forms one easily gets the result:

$$\overline{(\rho\rho')_{,t} Q^2} = r(w_1 - w_2)_{,r} + 3(w_1 - w_2). \tag{1.3}$$

In the simplest possible case $\overline{Q^2} = 1$ and this is referred to as the equation for the propagation of the density correlation function.

2. TRANSFORMATION OF THE FUNDAMENTAL EQUATIONS. DISTURBANCE MOMENTS

Assume that all the functions in the given turbulent field of flow are defined, continuous, and integrable in the intervals: $0 \leqq r \leqq +\infty$, $-\infty \leqq t \leqq +\infty$. If in some particular cases the integral $\int_{-\infty}^{+\infty} \ldots dt$ has no meaning, one may assume the interval $-T_1 \leqq t \leqq +T_1$, T_1 being a fixed quantity, arbitrarily large. The interval $0 \leqq t \leqq T_1 \leqq +\infty$, may be taken, as well. Multiply Eq. 1.3 by r^p, $p > 0$, integer, and integrate with respect to r from 0 to $+\infty$. Integrating (formally) by parts and applying the technique analogous to that in (2) gives the formula:

$$\int_0^\infty \overline{(\rho\rho')_{,t} Q^2} r^p dr = (w_1 - w_2) r^{p+1} \Big|_0^\infty + (2 - p) \int_0^\infty (w_1 - w_2) r^p dr. \tag{2.1}$$

Assume that the rate of decrease of the function $(w_1 - w_2)$ as $r \to \infty$ exceeds the rate of increase of r^{p+1} as $r \to \infty$ and $p = 2$. From Eq. 2.1 it follows that

$$\int_0^\infty \overline{(\rho\rho')_{,t} Q^2} r^2 dr = 0. \tag{2.2}$$

For $\overline{Q^2} = 1$ one easily gets:

$$\frac{d}{dt} \int_0^\infty \eta(r, t) r^2 dr = 0, \tag{2.3}$$

or for all values of t

$$M_1 = \int_0^\infty \eta(r, t) r^2 dr = \text{const.} = \int_0^\infty \eta(r, 0) r^2 dr = M_{10}. \tag{2.4}$$

Therefore, the first theorem of the conservation of the density disturbance moment is:

The density disturbance line-moment in a homogeneous, isotropic turbulent flow of a compressible viscous fluid remains constant, independent of time, and is uniquely determined by the initial density disturbance imparted to the fluid.

Notice, that as a consequence of (2.2) one has $\int_0^\infty K^{(2)} r^2 dr = 0$. Multiply Eq. 1.1 by r^k, $k > 0$, integer, and integrate with respect to r from 0 to $+\infty$. Applying integration (formal) by parts to the second and third terms on the left-hand side of (1.1) results in the expression:

$$2r^k \overline{\eta h}\Big|_0^\infty - k \int_0^\infty 2\overline{\eta h} r^{k-1} dr. \tag{2.5}$$

The first four terms on the right-hand side of (1.1) can be transformed in a similar way. The term containing the integral takes the form

$$2(k-2)^{-1}\left\{\left[r^k \int m dr - 2r^{k-1} \iint m dr dr + 2r^{k-2} \iiint m dr dr dr\right]\Big|_0^\infty - \int_0^\infty m r^k dr\right\}. \tag{2.5a}$$

Assume that the rate of decrease of the functions $\overline{\eta h}$, $(\overline{\beta f})_{,r}$, $\overline{\beta_{,r} f}$, $\int m dr$, as $r \to \infty$ exceeds the rate of increase of r^k as $r \to \infty$. Similarly, let the rate of decrease of $\iint m dr dr$ and $\iiint m dr dr dr$, as $r \to \infty$, exceed the rate of increase of r^{k-1} and r^{k-2}, respectively, as $r \to \infty$. Then for $k = 4$, Eq. 1.1 transforms into the formula:

$$\int_0^\infty [(\overline{\eta f})_{,t} + 2(K^{(2)} + m)] r^4 dr = \int_0^\infty F_1 r^4 dr = F_3(t), \tag{2.6}$$

where

$$F_1 = 2\overline{\beta N} - \tfrac{1}{3}(r\overline{\beta N})_{,r} - r\overline{\beta_{,r} N} + \overline{\beta_{,} f_{,r}}. \tag{2.6a}$$

Notice that the function F_1 contains the terms expressing the characteristic features of a compressible flow, that is, $\rho = \rho(r, t) \neq$ const., $\mu = \mu(r, t) \neq$ const. As is seen one cannot obtain from (2.6) an invariant in Loitsianskij's meaning. Similarly, one cannot obtain an invariant from the energy equation. Thus the only invariant in the case of a compressible fluid flow is the density-moment. Of course, one can speculate and some such consideration will be presented below. Let $\int_0^\infty F_1 r^4 dr$ have a limit. This means that $F_3(t)$ is a bounded function of t. The conditions under which such an integral has a limit are known. Let $F_1 r^4$ be a continuous single-valued function defined for $r \geqq 0$, $0 \leqq t \leqq +\infty$, which in the infinite interval $0 \leqq r \leqq +\infty$ is uniformly integrable. This condition is sufficient for the integral $\int_0^\infty \ldots dr$ to be a uniformly convergent, that is, it represents a

bounded function of t which is continuous. The condition of the uniform integrability is satisfied, if for each t,

$$|F_1 r^4| < \varphi(r),$$

where $\varphi(r)$ is an integrable function of r. If for instance, the function F_1 has the form $\exp[-f(t)r]$, $r > 0$, $f(t)$ being a non-negative function of t for $0 \leqq t \leqq +\infty$, then for each t

$$|F_1 r^4| = |\exp(-fr)r^4| < r^4 = \varphi(r).$$

Since $\varphi(r)$ is an integrable function of r, the above condition is satisfied. Call the integral $\int_0^\infty \overline{\eta f} r^4 dr = M_2$ the "momentum disturbance line-moment." As is seen this moment is a function of t, whereas in the case of an incompressible fluid it is an invariant (constant) for all values of t. Integrating both sides of (2.6) with respect to time between the limits zero and infinity one gets:

$$\int_{M_2(0)}^{M_2(\infty)} dM_2 = M_2(\infty) - M_2(0) = \text{const.} = M_{20}, \tag{2.7}$$

provided the integrals $\int_0^\infty \ldots dt$ have a limit. If these integrals have no meaning one may choose as the upper limit any value $t = t_1$, t_1 being arbitrarily large. Therefore, one can propose a statement that the total change of the momentum disturbance line-moment in a homogeneous, isotropic turbulent flow of a compressible viscous fluid is a constant quantity equal to the double time-line-integral from the polynomial of terms expressing the characteristic features of a compressible fluid, provided the double integral has a limit. Briefly, the total change of M_2 depends upon the magnitude of the disturbances introduced by the compressibility phenomena. It is doubtful whether this statement may find some application in a quantitative meaning, perhaps it may be applied in a qualitative way.

For an incompressible fluid F_1, $K^{(2)}$, m in (2.6) vanish and one obtains Loitsianskij's invariant $M_2 = \text{const.}$ An analogous procedure applied to (1.2) gives the following result:

$$M_2(\infty) - M_2(0) = \int_0^\infty dt \int_0^\infty F_4 r^2 dr = \text{const.} = M_{20}, \tag{2.8}$$

$$M_2 = \int_0^\infty \overline{J c_p c'_p \theta} r^2 dr, \tag{2.8a}$$

$$F_4(r,t) = \tfrac{1}{3}\overline{u^{-2}\eta^{-1}K^{(3)}[J(c_p c'_p\theta)_{,r} + (c'_p\rho^{-1}T'p_{,r} + c_p\rho'^{-1}Tp'_{,r})]}r - J\overline{\eta^{-2}\eta_{,r}\gamma\theta_{,r}} + \overline{(c_p\rho'^{-1}Tp'_{,t} + c'_p\rho^{-1}T'p_{,t})} + W. \tag{2.8b}$$

The first and second terms in (2.8*b*) are due to the characteristic com-

pressibility features ($\rho \neq$ const.), the third is due to $p_{,t} \neq 0$ and the last one to the dissipation function.

3. SCALES OF TURBULENCE

One may distinguish various intensities in the turbulent flow of a compressible viscous fluid: momentum intensity $\overline{(\rho^2 u^2)}^{\frac{1}{2}}$, density $\overline{(\rho^2)}^{\frac{1}{2}}$, enthalpy $\overline{(c_p{}^2 T^2)}^{\frac{1}{2}}$, viscosity $\overline{(\nu^2)}^{\frac{1}{2}}$, pressure, etc. Similarly, one may distinguish various length-scales, as for example, velocity length-scale,

$$L_1 = \overline{(u^2)}^{-1} \int_0^\infty f(r, t)dr, \tag{3.1}$$

density length-scale,

$$L_2 = \overline{(\rho^2)}^{-1} \int_0^\infty \eta(r, t)\, dr, \text{ etc.} \tag{3.2}$$

Let us choose a conventional length-scale,

$$L^3{}_{*\rho} = \int_0^\infty \overline{(\rho^2)}^{-1} \eta r^2 dr, \tag{3.3}$$

or with the use of (2.4)

$$\overline{\rho^2} L^3{}_{*\rho} = M_{10}. \tag{3.4}$$

Hence one has another form of the theorem presented above:

> The product of the square of the density intensity by the third power of the density length-scale is a constant in a compressible viscous fluid.

Notice that although both factors on the left-hand side of (3.4) depend on time, M_{10} is an absolute constant independent of both t and r. Introducing the notions of the average intensities:

$$\overline{u_0{}^2} = t_1{}^{-1}{}_{t_1 \to \infty} \int_0^{t_1} \overline{u^2}(t)dt, \tag{3.5a}$$

$$\overline{\rho_0{}^2} = t_1{}^{-1}{}_{t_1 \to \infty} \int_0^{t_1} \overline{\rho^2}(t)dt, \text{ etc.,} \tag{3.5b}$$

and a conventionally chosen length-scale

$$\overline{\rho_0{}^2}\, \overline{u_0{}^2} L^5{}_{*\rho u} = \int_0^\infty \overline{\eta f} r^4 dr = M_2, \tag{3.6}$$

one can express the controversial statement, presented above, in the form:

$$\overline{\rho_0{}^2}\, \overline{u_0{}^2} [L^5{}_{*\rho u}(\infty) - L^5{}_{*\rho u}(0)] = M_{20}. \tag{3.7}$$

Similarly, introducing the notions

$$\overline{c_{p_0}{}^2} = t_1{}^{-1}{}_{t_1 \to \infty} \int_0^{t_1} \overline{c_p{}^2}(t)dt,\ \overline{T_0{}^2} = t_1{}^{-1}{}_{t_1 \to \infty} \int_0^{t_1} \overline{T^2}(t)dt, \tag{3.8}$$

one can put down

$$J\overline{c_{p_0}{}^2}\,\overline{T_0{}^2}[L^3{}_{\bullet cpT}(\infty) - L^3{}_{\bullet cpT}(0)] = M_{30}. \tag{3.9}$$

4. FINAL REMARKS

After completing and sending this note the author noticed the paper of Chandrasekhar (3) where an invariant analogous to (2.3) was derived. The author would like to mention that he presented twice in the past the derivation of (2.2) and (2.4), before the Meetings of the American Mathematical Society: University of Kansas, Lawrence, Kansas, April 29–30, 1949 in his talk on "The Invariant Theory of Isotropic, Homogeneous Turbulence in Compressible Fluids" and University of Chicago, November 25–26, 1949, "On the Extension of Kolmogoroff's Theory of Turbulence to Compressible Fluids."

In his paper, Chandrasekhar presents a physical meaning of the density moment invariant.

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NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

PROPERTIES OF SOILS

To an electrical power company which has extensive underground installations, the mechanical strengths, waterproofness, and thermal conductivities of soils are matters of considerable practical importance. Accordingly, the Philadelphia Electric Company gave The Franklin Institute Laboratories the problem of finding or developing methods and materials to improve these properties, preferably by the injection of chemicals into the soil. The problem was intriguing since supposedly "solid" soil underfoot actually contains from 30 to 50 per cent of voids filled with air or water, and the solid part of soil may be anything from colloidal clay particles, through sand, to boulders, or a mixture of all three.

Actually, it was found that the injection of asphalt emulsions to shut off the flow of water through soils has been used successfully in

Fig. 1. The sand recommended by the Laboratories being used as a backfill material on the Southwark-island Road job.

California, Egypt, and elsewhere, to prevent the loss of water by seepage under dams. As much as 10 per cent of the water impounded by a reservoir, which might otherwise be lost by seepage, is thus saved. The load-bearing strength of water-logged or low density soils under building foundations and structures has also been improved commercially, in this case by injecting chemicals which react in the soil to produce insoluble calcium silicate, which binds the soil particles together.*

Fig. 2. A conference in the field between the Company and Institute engineers, illustrating the close liaison and cooperation which was an important factor in the successful completion of the task. Left to right: E. Thelen, F. H. Gaskins, D. H. Russell of the Institute; L. H. Fink and J. A. Jones of Philadelphia Electric Company.

The control of thermal conductivity of soils, however, required more study, since little has been reported in the literature on this subject. Test methods were devised and through laboratory work and study, practical correlations were found by which thermal conductivities of soils could be predicted approximately from a knowledge of their densities, water contents, and general composition. It was predicted in the laboratory, and found in practice, that the practical materials with the best thermal conductivities are quartz sands whose particle-size distribution permits them to be densely packed.

* A "soil permeability tester" was described in this JOURNAL, Vol. 253, p. 340 (1952).

At this time, in the course of constructing a new underground conduit, the Philadelphia Electric Company uncovered a halfmile portion of the route under the new Penrose Bridge where the soil, full of cinders, ashes, and coal dust, had very low thermal conductivity. Since the amount of current a cable can carry is limited by the rapidity with which the surrounding soil can carry off the heat developed in the cable, the Company's practice in such a situation has been to replace the soil in the immediate vicinity of the conduit with a backfill of higher thermal conductivity. The Laboratory's researches had shown that a certain commercially available concrete sand, which was much lower in cost than the backfills the Company had previously used, would provide a good approximation of the superior thermal properties characteristic of pure quartz sand. Philadelphia Electric Company expects to use this laboratory-proved backfill material in future jobs where improved thermal conductivity is important.

EDMUND THELEN

NOTES FROM THE NATIONAL BUREAU OF STANDARDS *

IMPROVEMENT OF ACRYLIC AIRCRAFT GLAZING BY STRETCH-FORMING

Acrylic plastic glazing has been used for many years in astrodomes, gun turrets, antenna covers, and other transparent curved enclosures in military aircraft. However, in spite of its good weathering and optical properties and the ease with which it can be formed into shapes with compound curvature, this material has several disadvantages, such as low impact strength and craze cracking. Perhaps the most serious of these is its tendency to craze under stress, especially in the presence of organic solvents. This results not only in reduced visibility but also in lowered resistance to both steady and impact loads.

Until now, little information has been available concerning the effect of forming on the crazing and strength properties of the acrylic plastic sheet. To provide the necessary data, B. M. Axilrod and associates of the National Bureau of Standards recently made a study[1] of the effects of moderate biaxial stretch-forming on acrylic plastic glazing. Results of their investigation, which was sponsored by the National Advisory Committee for Aeronautics, indicate that suitable prestretching may provide an effective means for improving the crazing resistance of the material.

Measurements on a typical astrodome had shown that the material at the apex is biaxially stretched in the forming process about 40 to 50 per cent in the plane of the sheet of material; the initial NBS studies were therefore made on samples stretched approximately this amount. To obtain a flat sample uniformly stretched in two dimensions, a sheet of the plastic was first heated to a temperature in the rubbery range for the material (120 and 140 C. for the general-purpose and heat-resistant grades, respectively). The sheet was then clamped to the open end of a cylindrical forming vessel, and a partial vacuum was produced quickly in the vessel to force the sheet down into the chamber. An open-ended cylindrical tube, or form, was inserted into the plastic "bubble," and the vacuum was destroyed, causing the heated rubbery plastic sheet to retract around the form. After the plastic had become rigid, it was removed from the forming vessel; it then had the appearance of a top hat. The test specimens were taken from the flat top portion of the "top hat."

Specimens from the formed pieces as well as from the unformed portions of the same sheets were subjected to various tests, including

* Communicated by the Director.

[1] A complete report of this work will be published soon as a National Advisory Committee for Aeronautics Technical Note, and a brief account will also appear in the *Journal of Research* of the National Bureau of Standards.

standard tensile tests, stress-solvent crazing with benzene, long-time tensile loading, and accelerated weathering. The specimens used for the long-time tensile loading and stress-solvent crazing tests had a tapered central portion. This design resulted in a gradation of stress in the loaded specimen and made it possible in the solvent crazing tests to obtain a threshold crazing stress by testing only a few specimens.

In the long-time tensile tests, values of the threshold stress were obtained as a function of time by observing the tapered specimen at intervals after the load was applied. The threshold stresses for the different specimens were plotted against time; from the graph, average threshold values for 1, 10, and 100 hr. were obtained. As the crazing behavior of acrylic plastic sheet is known to be affected by temperature and relative humidity, the long-time tensile loading tests were performed in a controlled-atmosphere room operated at 23 C. Half of the tests were made at 50 per cent relative humidity; the other half were made at about 95 per cent relative humidity.

The results of the NBS experiments indicate that biaxially stretch-forming the acrylic plastic 50 per cent does not affect its tensile strength or secant modulus of elasticity in tension. However, the elongation at failure is greatly increased—from approximately 10 per cent to about 60 per cent.

The appearance of the tensile specimens after the tests led to some interesting conclusions. First, it was observed that the broken tensile specimens of the formed pieces have a laminar character unlike the unformed material. Next, an examination of the fracture surface on each of the broken tensile specimens showed that in every instance there was a small mirror-like area oriented perpendicularly to the tensile load. From an examination of broken solvent-crazed specimens and other evidence, it was concluded that fracture in the acrylic material begins in the mirror area and that this area is an extension of a crazing crack.

The effect of the biaxial stretch-forming on the threshold stress for stress-solvent crazing with benzene was to increase this stress about 75 per cent for both the general-purpose and heat-resistant grades. Also, there was a tendency for the crazing cracks to be somewhat finer and more closely spaced on the formed as compared to the unformed specimens.

In the long-time tensile loading tests, the threshold stresses for crazing after 100 hr. of loading were about 2700 and 3700 psi. for unformed material of the general-purpose and heat-resistant grades, respectively. The threshold crazing stresses of all of the formed samples were about 40 to 50 per cent greater than the stresses for the corresponding unformed material. Although no significant difference in threshold stress due to relative humidity was noted, the nature of the crazing at the two relative humidities was markedly different. The cracks at 95 per cent relative humidity appeared finer and more closely

spaced and were almost always noticeably shorter than those at the lower relative humidity.

The improvement in the crazing properties of acrylic plastic sheet produced by moderate biaxial stretch-forming suggests that enclosures made from stretched sheets have superior crazing and strength properties as compared to enclosures formed with little or no stretching. As an alternative to the use of prestretched material to achieve improved craze resistance and toughness in acrylic enclosures, there is the possibility of preparing a more highly stretched enclosure directly, such as by forming a larger and more deeply drawn enclosure than required and then using only the central portion of the formed piece. Either method would improve the craze resistance, particularly at the rim, where there is likely to be stress concentration and where contact with solvents or adhesives used to seal the enclosure is quite likely; in a normally formed enclosure, the craze resistance is a minimum at the rim. The laminar structure of the stretched acrylic sheets also offers the possibility of obtaining resistance to shattering of pressurized acrylic canopies by shrapnel without the necessity of employing the heavier and more expensive acrylic laminate made with a safety-glass type of vinyl interlayer.

TITANIUM-DIOXIDE RECTIFIERS

A new type of rectifier recently developed by the National Bureau of Standards promises to be the first major improvement in metal-oxide rectifiers since their introduction in 1926. The new rectifier is composed of a layer of semiconducting titanium dioxide, a sheet of titanium metal, and a counterelectrode of some other conducting metal. Although the development is still in an early stage, preliminary investigations have shown that the units withstand voltage in the reverse direction reasonably well and that their properties are satisfactory at elevated temperatures. Both the initial development and subsequent detailed exploratory investigations are the work of R. G. Breckenridge and W. R. Hosler of the NBS Solid State Physics Laboratory.

The earliest practical type of metallic rectifier was the copper-cuprous oxide rectifier, invented in 1926 by Grondahl, which consists of a copper sheet covered with a layer of cuprous oxide, and a counterelectrode on top of the oxide layer. Many extensive investigations have been undertaken to develop similar rectifiers, but until now no other metal-oxide film combinations have been found that were feasible, although several non-oxide types have been produced—e.g., the selenium and magnesium-copper sulphide rectifier.

The new NBS rectifiers are prepared by forming a layer of titanium dioxide on a sheet of titanium metal and then applying a counterelectrode to the oxide surface. Two processes have been devised to form the oxide layer. The first process involves heating the titanium metal first in oxygen gas and then in hydrogen gas. The other—an improved

version of the first—consists in heating the titanium metal in steam at elevated temperatures.

In the first process, $\frac{1}{2}$-in. squares of commercial titanium metal sheet, 0.020 in. thick, are polished and heated in oxygen gas to form the coat of titanium dioxide. A thin, tightly adherent coat of oxide is obtained after a treatment at 800 C. for about 2 hr. The oxide layer formed in this manner becomes a very poor conductor of electricity; it is made into a semiconductor with a much greater conductivity by heating in hydrogen gas, which causes a loss of oxygen. A study of the reaction showed that heating in one atmosphere of hydrogen at 500 C. for 15 min. would produce sufficient conductivity.

After the hydrogen treatment, a counterelectrode is electroplated on the desired rectifying surface of the oxide by a-c. plating techniques. A number of metals have been tried successfully as counterelectrodes, including silver, gold, tin, nickel, copper, zinc, and cadmium, although silver has been used for the majority of the work. When the current is measured for various applied voltages, it is found to flow much more readily in one direction than the other; hence, the combination acts as a rectifier.

Rectifiers produced by the process are electrically satisfactory; however, the two-step process is difficult to control and, in addition, the oxygen and hydrogen gas tends to dissolve in the heated titanium metal and make it brittle. The second process of oxide formation, using water vapor, produces the semiconducting oxide layer on the metallic titanium in one step. The most satisfactory films are formed by heating similar titanium plates in steam at 600 C. for about 3 hr. The counterelectrodes are then electroplated in the same manner to form a finished unit. This process produces a rectifier with improved electrical properties but lacks the undesirable embrittlement accompanying the other method.

While the titanium-dioxide rectifiers are still in a very early stage of development, some of their properties have aroused considerable interest. The units can withstand a reverse voltage of about 20 volts per plate. In addition, they have good properties at elevated temperatures; their performance is actually improved with increasing temperature up to about 150 C. Detailed studies have not been made of their operating life, but tests thus far are very encouraging.

The NBS titanium dioxide rectifiers bear a physical resemblance to the copper oxide type; however, there are fundamental differences between them. For example, the direction of easy flow of current is opposite in the two types. In the titanium dioxide rectifier, the electrons flow from the titanium metal base plate to the counterelectrode. The mechanism of conduction in the metal oxides is also different. In cuprous oxide the charge carriers are "holes" or electron vacancies in the lattice, while in titanium dioxide semiconductors the charge carriers are free electrons. Finally, the "barrier layer," or asymmetrical poten-

tial that must be surmounted by the charge carriers, apparently is located near the counterelectrode-oxide interface for the NBS type, while there is evidence that in the cuprous oxide device the barrier is located at the base metal-oxide surface.

NOTE: This report is summarized from a paper presented at the Washington Meeting of the National Research Council's Conference on Electrical Insulation, October 29 to 31, 1951.

FIRE TESTS OF ESCALATOR SHUTTERS

Unprotected escalator openings in department stores and other large, multistoried buildings may allow a fire to spread with great rapidity. To reduce this type of hazard, the Building Exits Code of the National Fire Protection Association recommends that each moving stairway above street level be equipped with a rolling shutter that will automatically close the top of the stairway when fire or smoke is detected in its vicinity. Automatic shutters of this kind have been installed in many buildings, but definite information on their effectiveness has been lacking. Recently N. D. Mitchell, E. W. Bender, and J. V. Ryan of the National Bureau of Standards completed fire tests[1] of escalator shutters submitted by manufacturers, providing information of interest to architects and builders, as well as regulatory bodies concerned with specifications or building code requirements.

In general, the shutters tested consist of galvanized steel slats which travel on rollers in steel guide rails. Automatic closure may be obtained by any standard fire or smoke-sensitive system.

Three fire tests were made: an exploratory test to determine the adequacy of the shutter and guides alone, and two full-scale tests in which the supporting frames and runways were used. The shutters were installed over a floor-test furnace, and fires were applied to the underside of the installation. Temperatures were measured by means of chromel-alumel thermocouples protected by porcelain insulators and encased in wrought-iron pipes sealed at one end. The furnace temperature was raised to 1700 F. in 1 hr., and to 1925 F. in 3 hr. in accordance with the ASA standard method for fire tests. The tests were discontinued at the end of three hours.

In each of the tests the shutters sagged, the guides were somewhat deformed, and the rollers were damaged by burning and loss of lubrication. However, as the fire did not spread up through the shutters, they were considered to have successfully performed their function. Retraction after the fire was difficult, but this did not affect the main function of the shutter. As a result of the tests, design changes have been recommended, particularly to allow for thermal expansion in the guide rails.

[1] For further details, see "Fire Resistance of Shutters for Moving-Stairway Openings," by Nolan D. Mitchell, Edward W. Bender, and James V. Ryan, NBS Building Materials and Structures Report 129, available from U.S. Government Printing Office, Washington 25, D.C., at a cost of 10 cents.

THE FRANKLIN INSTITUTE

MUSEUM

History classifies the growth of civilization by periods—the Stone Age, the Bronze Age, the Iron Age, and the Steel Age. Our country began its growth during the Iron Age, 300 years ago. The first attempt to make iron in North America was made by the Virginia Company in a blast furnace at Falling Creek, near Richmond, Va. It is doubtful whether the furnace ever got into sustained production, for the massacre of the little settlement and the destruction of all its facilities in 1622 put an end to the experiment.

The second attempt at iron production in America, twenty years later, fared better. John Winthrop, Jr., son of the first governor of Massachusetts, organized an iron works at Saugas, on the outskirts of Lynn. Operating only during the spring, summer, and fall months when weather permitted, its production is variously reported to have been from 5 to 7 tons per week. The initial capital of the company was 1000 pounds sterling. This was the cradle of the iron and steel industry of the United States.

The early Iron Masters knew only cast iron and wrought iron, the product of the blast furnace and the forge. Most of the products requiring ductility and formability were made by puddling, a cumbersome method of eliminating the carbon and silicon of the pig iron, and a mechanical method of squeezing out the included slag before the final rolling into shape. The puddlers were a sturdy race who rabbled the molten mass of iron into balls and passed them on to the squeezer.

The industry struggled through two centuries before the discovery of the pneumatic process of making steel from molten iron by Sir Henry Bessemer in England and William Kelley in America. This was followed by the inventions of Siemens, a German, and the brothers Martin, Frenchmen, resulting in the development of the open hearth.

The first fuel employed by the industry was charcoal. The consumption of wood for this purpose was colossal. The Warwick Furnace in Pennsylvania is reputed to have cut 240 acres of timberland for the charcoal operation of that furnace, in one year. Generally speaking, one quarter acre of hardwood timber produced one ton of pig iron. England preceded us in the use of coal fuel for the blast furnace. Abraham Darby completed the final transition from coal to coke in the first half of the 18th century. The use of anthracite was firmly established by David Thomas at the Lehigh Crane Iron Works. Thomas arrived in this country from Wales in 1838. Within twenty years of his arrival 93 of the 112 blast furnaces operating in Pennsylvania were using anthracite as their smelting fuel.

The progress of the industry was impressive. In the year 1810, the total production of iron in the United States was 53,908 tons, almost half of which was produced in Pennsylvania. One hundred years later (1910) production had reached 23 million tons. Today, the annual output is approximately 100 million tons. Every automobile that passes has 1½ tons of iron and steel; a freight car has 17 tons; the Empire State Building has 50,000 tons; the Golden Gate Bridge 107,000 tons. In a single railroad track between New York and Philadelphia there are 28,000 tons of steel; 700,000 tons are used in nails each year, and over 100,000 tons in nuts and bolts. Coat hangers account for 30,000 tons while ladies carry 6000 tons on their heads in the form of bobby pins.

An industry which supplies so many needs in our daily life deserves to be better known among the general public, and to the end of furnishing Museum visitors with a comprehensive picture of the industry and its significance, the Bethlehem Steel Corporation has provided an admirable series of exhibits. These show how steel is made, and the properties and uses of steel. Light, color, and motion have all been skillfully employed to make the display as attractive as possible, and there is a good proportion of those visitor-operated exhibits which are characteristic of the Museum. This handsome room is proving to be a center of attraction, and we recommend all members to make a point of visiting it at the earliest opportunity.

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JOURNAL OF THE FRANKLIN INSTITUTE

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MANDEVILLE, C. E., E. SHAPIRO, R. I. MENDENHALL, E. R. ZUCKER AND G. L. CONKLIN: Radiations from Zr^{97} and Nb^{97}.
HETENYI, M.: Application of Maclaurin Series to the Analysis of Beams in Bending.
SHEN, D. W. C. AND H. N. G. BROADBENT: Analysis of Partly Symmetrical Machines by Means of Unitary Transformation.
GROSS, ERIC T. B.: Unbalances of Untransposed Overhead Lines.
MOON, PARRY AND DOMINA EBERLE SPENCER: Theory of the Photic Field.
MOON, PARRY AND DOMINA EBERLE SPENCER: Some Applications of Photic Field Theory.
SAIBEL, EDWARD AND WINSTON F. Z. LEE: Vibrations of a Continuous Beam under a Constant Moving Force.

BOOK REVIEWS

BASIC MATHEMATICS FOR ENGINEERING AND SCIENCE, by Van Voorhis and Haskins. 608 pages, diagrams 14 × 21 cm. New York, Prentice-Hall, Inc., 1952. Price, $5.75.

Educators and publishers are increasingly concerned with the rising demand for engineers. Their answer to the problem is greater proficiency in the training of science students by speeding up the introduction of specialty courses (particularly mathematics, the basic prerequisite) during the freshman year. "Unified" and "Integrated" courses give the departments of science and engineering an early hold on the student during his most formative years.

The present, unified text not only reviews just about every important phase of algebra, while actually developing analytical geometry, but it introduces and develops trigonometry simultaneously. And while the student becomes acquainted with the necessary mathematical tools, his imagination is stimulated by numerous references to such fields as chemistry, physics, astronomy, statics, dynamics, ballistics, and statistics. Add to these some calculus in later chapters and you have a "practical" volume that must inevitably lead to familiarity with the basic concepts and notions in those fields. Many topics from geometry help refresh the students' memory and advanced notation is employed whenever feasible. The first chapter alone introduces the summation symbol, first and second derivative notation, substitution for upper and lower limits, functions of one or more variables, the scientific notation of numbers, approximate numbers and errors, and the use of formulas through substitution of decimal values. Later chapters include vectors, infinite series, limits, determinants, even spherical and cylindrical coordinates and the book closes with an entire chapter on probability and statistics.

A good teacher, well versed in the many fields from which the author draws, can make such a course a great experience for the college freshman. He can select from two thousand individual exercises and stimulate class-room discussion by extensive use of three hundred "Questions for Discussion" which are distributed throughout the book; they provide a novel answer to the request of Modern Education to supplant formal lectures by informal discussion, even in mathematics courses. The great diversity of all this material appears sometimes forcibly constrained into catch-all chapters and may make this a difficult volume to teach. Given a mature and experienced teacher, however, a course based upon this text will enable even the many inadequately prepared college freshmen of today to enter as early as in their second semester into their respective fields of specialization—indeed a major accomplishment.

Some chapters may appear over-saturated with concepts and definitions from applied fields and thus confuse the beginner. Alert students, however, will be quick to discover the only real weakness which is wide-spread in similar texts: many diagrams are presented without proper scales or even drawn out of proportion (Fig. 12.17 at the origin, 12.19 at the asymptotes, etc.). In addition, there is the usual crop of mistakes, unavoidably encountered in a first printing. Taking everything into consideration, the volume shows that author and publisher have jointly succeeded in taking some steps in the right direction toward a successful text.

CARL HAMMER

STATISTICAL THEORY WITH ENGINEERING APPLICATIONS, by A. Hald. 783 pages, diagrams, 17 × 25 cm. New York, John Wiley & Sons, Inc., 1952. Price, $9.00.

STATISTICAL TABLES AND FORMULAS, by A. Hald. 97 pages, 22 × 28 cm. New York, John Wiley & Sons, Inc., 1952. Price, $2.50.

Dr. Hald treats Statistical Theory in a mathematical way, but with the engineer in mind. As the author states,"The mathematical techniques employed are reasonably elementary, and only a knowledge of standard differential and integral calculus is assumed." New concepts are introduced slowly, and the tome is supplied with numerous examples aside from a separate volume, published in conjunction with the text, that includes a summary of the most important formulas, a comprehensive set of tables, examples and references. A large number of references

are scattered throughout the book itself. Sections on Notation, List of Auhtor References, Index of Symbols and Formulas, and Subject Index are provided.

The main body of the book is composed of twenty-five chapters in which the following topics are treated: calculus of probability, representation of observations, empirical and theoretical distributions, the normal, skew, and sampling distributions, the distribution of the mean, variance, range and variance ratio, the χ^2- and t-distributions, statistical control, analysis of variance, design of sampling investigations and experiments, regression analysis, two-dimensional normal distribution, multi-dimensional correlation, the binomial, Poisson and multinomial distributions, the χ^2-test, sequential analysis and a concluding chapter on the main points of a statistical analysis.

Mention is made of punched cards, time series, random numbers and many other topics not usually treated in books on statistics. In fact, the subject is thoroughly covered and effectively so. The supplementary set of tables includes random sampling numbers which are not the usual table of Tippett's.

In a book of this size notation becomes important and frequently confusing. The index of symbols is extremely helpful in this respect. It may help those familiar with the subject to know that the text has been influenced by Professor R. A. Fisher and Dr. W. A. Shewhart, but the examples are drawn from Dr. Hald's experience. A considerable history of the subject is gleaned from reading the background material presented and what is said of the authors referenced. A large number of figures and tables illustrate the concepts and computational methods, and are used very effectively to summarize sets of related formulas.

An engineer desiring a cursory knowledge of the subject might find Hald too exhaustive, but he who applies statistics with only a cursory knowledge is in for trouble. The work is excellent as a text and particularly as a reference book.

DONALD B. HOUGHTON

SYMPOSIUM ON RADIOBIOLOGY, edited by James J. Nickson. 465 pages, diagrams, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1952. Price, $7.50.

This book contains the papers and discussions presented at the Oberlin Symposium on Radiobiology in June, 1950. Authored by 26 leading men in the field, including three foreign scientists, the book is concerned with the basic aspects of radiation effects on living cells. It is a collection of 23 essays beginning with "Radiation in Living Matter: The Physical Processes" and ending with "Analysis of Mammalian Radiation Injury and Lethality." It is to be hoped that this last chapter will find little application.

The plan of the book is to present the existing state of knowledge in radiobiology in four parts. The first four papers comprise a survey of the physical interaction of ionizing radiation and matter. The next five attempt to explain the associated chemical changes. Nine are devoted to biochemical effects and the last five discuss the changes occurring in living tissue. These divisions are somewhat arbitrary and there is some overlapping of material. However, this was to be expected since each essay was to be a thorough treatment of the subject.

The book aims at bringing together fundamental ideas and concepts, at directing "thought towards the solution of problems currently existing in the field of radiobiology" and at pointing out major gaps in present knowledge. It is quite obvious that the authors are keenly aware of these gaps. One of them laments, "A biological system is a theorists' nightmare." Only a knowledge of elementary nuclear physics is required with the exception of one chapter in which the reader is exposed to quantum statistics. The theoretical development in this chapter is out of place in a book which is largely non-mathematical and in which the chief concern is explanation and understanding of phenomena, not derivation of formulae.

It is pleasant to report that the editors have, in the main, achieved their aims. The papers are excellently written although there were some in which several terms could have been defined and captions made more specific for the general reader. There are only a few confusing typographical errors and the quality of the printing meets the usual high standards of the publisher. This collection of essays should prove valuable in stimulating an interest in the exact nature of radiobiological phenomena and in presenting a well rounded picture of radiobiology in a highly readable form.

LEONARD MULDAWER

ADVANCED ANTENNA THEORY, by Sergei A. Schelkunoff. 216 pages, diagrams, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1952. Price, $6.50.

As one scans the *Proceedings* of the various professional electronic groups published during the past half-decade, numerous advances in antenna theory are apparent. The number of papers on this subject appearing since the War attests to the importance of these advances. In the spectacular growth of electronics and communications the importance of the transmitting and receiving antenna has not been overlooked. The extension of practice to the high frequencies and to microwaves has provided the practical impetus for these researches by supplying an unlimited number of new problems to challenge the engineer and theorist.

Schelkunoff has clearly established himself as one of the leading authorities on electromagnetic theory as it is applied to communications devices. His books on electromagnetic theory and the applications of mathematical principles are well known. His special preoccupation with antenna problems undoubtedly stems from assignments at the Bell Telephone Laboratories and other practice. This close relation to practical, commercial applications is partly responsible for the objective quality of Schelkunoff's writings. As one examines the explanations in the text, the problems, the appendices, the references in the recently published "Advanced Antenna Theory" these qualities are detected.

The new book does not attempt a review of antenna forms and applications, but instead is devoted to newly developed mathematical methods and concepts. The historic work of Pocklington and Hallén followed by Stratton, Chu and Schwinger are integrated with Schelkunoff's own concept of the conical antenna. The theory of spheroidal antennas is developed as an example of what may be called "the resonator theory of antennas." Hence, the mathematical justification of an intuitively evident relation among antennas, transmission lines and waveguides is established. For completeness, an alternative approach to the solution of the antenna problem is treated extensively employing Hallén's circuit theory of antennas.

Schelkunoff's familiarity with generalized circuit operations and with the mathematical equivalence of certain electrical networks to field phenomena permits him to use circuit illustrations as an aid to the understanding of field analyses. The parameter terms, resistance, reactance, impedance, admittance, are frequently the dimensions to which an analysis is finally reduced. Suggestions are frequently given to indicate ways of realizing the theoretical requirements for specific current and charge distributions.

An understanding of the analytical methods demonstrated in this book permits the student to compute various field components, current densities, and impedances associated with special physical configurations which might comprise an antenna or portion thereof. Using these methods, it is felt certain problems can now be managed with less effort than was previously the case, and this is a tribute to Schelkunoff's simplification of the mathematical techniques.

The book is an appropriate volume to form a part of the Applied Mathematics Series, and it may possibly interest the mathematician more than those directly responsible for the development of antennas. However, technical developments of this nature are becoming so complex as to require, or at least profit from, cooperative research involving men of diverse specializations. Therefore, Schelkunoff's disclosures in this single volume may be read by an unexpectedly large group.

C. W. HARGENS

CALCULUS OF VARIATIONS WITH APPLICATIONS TO PHYSICS AND ENGINEERING, by Robert Weinstock. 326 pages, diagrams, 16 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1952. Price, $6.50.

In his exposition of the techniques of the calculus of variations, the author's own stated aims are: (1) To provide for the senior or first-year graduate student in mathematics, physics or engineering, an introduction to the ideas and techniques of the calculus of variations; (2) to illustrate the applications of the calculus of variations in several fields outside the realm of pure mathematics. The material of the first seven chapters has been used as the subject matter of a 10-week course in the Mathematics Department at Stanford University.

The elementary problem of the calculus of variations is introduced via several physical examples. The Euler-Lagrange differential equation for the function $y(x)$ which extremizes

the definite integral $\int_{x_1}^{x_2} f(x, y, y')dx$ is derived. The corresponding equation for an integrand function of several dependent variables is also derived, and the case of undetermined end points is considered. The extremization of double integrals and of n-tuple integrals over n-dimensional space are treated in detail in later chapters.

A chapter is devoted to the role of the calculus of variations in classical dynamics. Hamilton's principle is presented in its ordinary and extended forms; the latter covers those cases in which there exist forces in addition to those derivable from a potential. The principle is later applied to derive the equations of motion for continuous distributions of mass, including as examples the vibrating string and the vibrating membranes.

Eigenvalue-eigenfunction problems are introduced via the example of the vibrating string. The example is generalized in the presentation of Sturm-Liouville systems as they evolve from isoperimetric problems.

Perhaps the high points of the book are the author's emphasis on isoperimetric problems and the exposition of Courant's maximum-minimum principle. The power of the latter in treating the difficult question of whether an extremum constitutes a maximum or a minimum is demonstrated by an examination of the membrane eigenvalue problem.

The book covers many examples not usually encountered in elementary treatises on the calculus of variations. In questions of mathematical rigor the student must consult the classical expositions of this subject. The author's elimination of the δ notation and method is open to serious question, since it makes difficult for the student a transition from classical disciplines in the subject to the examples posed by this book; this procedure also removes a necessary manipulatory tool without which fundamental developments in the subject are difficult. However, the book does fulfill the author's aims by providing an introduction to the subject, followed by extensive applications in physics and engineering. By this standard the book is a valuable contribution.

HOWARD H. BROWN

ULTRAVIOLET RADIATION, by Lewis R. Koller. 270 pages, diagrams, illustrations, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1952. Price, $6.50.

The visible light spectrum and its properties are familiar to many scientists and engineers. Not so, however, that part of the electromagnetic energy spectrum in the region 40–4000 Å, termed the "ultraviolet." Physicists, engineers, and specialists in fields other than radiation are often confronted with practical problems regarding the nature and effects of ultraviolet radiation, as has been evidenced by the numerous inquiries received by the author and his company over many years. This book attempts to provide answers to these many questions raised by persons who work with ultraviolet radiation. By no means a comprehensive or basic book, it provides many useful data on sources and components which are commonly available and widely used.

The eight chapters of the book consider the following topics: definitions and units of measure; arcs; incandescent sources; solar radiation; transmission, reflection; applications and effects of ultraviolet radiation; and detection of ultraviolet. For each of the major sources of radiation the author presents currently available charts and graphs showing the energy distribution and relative efficiency; as well as descriptions of the physical features and operating characteristics of particular sources, especially lamps. The chapter on solar radiation is particularly interesting; it considers daily and seasonal variations in ultraviolet radiation as well as the dependence upon geographical location and altitude.

The action of many commonly used absorbing media and the properties of reflecting surfaces are described, again by numerous charts and tables. The former include glasses, quartz, plastics, filters and skin protective coatings (sun-tan lotions and salves). The latter include evaporated films, glasses, pigments and skin.

This book should find wide acceptance among scientific workers in the field of ultraviolet radiation and its application.

S. CHARP

THE ORIGIN OF LIFE AND THE EVOLUTION OF LIVING THINGS, by Olan R. Hyndman. 648 pages, 16 × 24 cm. New York, Philosophical Library, 1952. Price, $8.75.

It takes an inordinate amount of courage to run counter to the accepted theories now being taught. This the author, Olan R. Hyndman, possesses for he proposes this type of a theory and his book of some 650 pages is an acute treatment of a fascinating and absorbing topic—the origin of life.

For many decades biologists have held that a fortuitous mutation is the fundamental mechanism of evolution. In his new theory Dr. Hyndman proposes that the fundamental influence is environmental in nature and the changes in the germ plasm—as he calls it—are wholly subject to the operation of natural (physical) laws. He holds that the genes are stimulable, that is, subject to change and the change is structural as opposed to the mutative change.

The "Origin of Life" is a difficult, albeit absorbing, book and though the environmental approach may not be accepted, it presents a thoroughly stimulating picture of how man began.

I. M. LEVITT

PANORAMA OF SCIENCE, 1952, edited by Webster Prentiss True. 422 pages, illustrations, 15 × 23 cm. New York, The Series Publishers, Inc., 1952. No price.

That well known encyclopedic work on the sciences, *The Smithsonian Series*, is keeping abreast of the times by issuing an annual supplement under the title of *Panorama of Science*. The original volumes in the series were written and edited by members of the Smithsonian staff, acknowledged authorities in their fields. The task of bringing the subjects up to date by means of annual supplements is beyond the capacity of any one man. Mr. W. P. True, who was formerly chief editor at the Smithsonian Institution, has endeavored to solve the problem by selecting twenty-seven articles which appeared in scientific literature during the past year. Since the volumes in the original series were not designed to meet the needs of specialists, the editor of the supplement has wisely chosen those articles which have a minimum of technical language. Little fault can be found with the current choice, although one might question whether an article on the construction of archaelogical dioramas comes within the compass of science or will have an appeal for many laymen.

Obviously not all the intricacies of modern science can be covered in one medium sized volume by selections of this sort, and the over-all effect is one of scrappiness, but there is a definite gain in having a few phases of science adequately covered when there are distinct advances to report. It is interesting to observe that of the four articles which peer into the future, two are from the 125th anniversary issue of this JOURNAL.

T. C.

THE NATURE OF SOME OF OUR PHYSICAL CONCEPTS, by P. W. Bridgman. 61 pages, 16 × 24 cm. New York, Philosophical Library, 1952. Price, $2.75.

Any science, as it evolves, must continuously re-examine its fundamental concepts to make clearly apparent to all working in that science the precise meaning of these concepts. For many years Professor Bridgman has somehow found the time apart from his important research work to pursue the analysis of the concepts basic to the physical sciences. To his clear thinking and lucid writing in this field we owe a great debt.

His latest contribution, the book presently at hand, contains three lectures which he delivered at the Department of the History and Philosophy of Science, at City College, University of London, in 1950. Unlike his earlier "The Nature of Physical Theory," which was also based on a set of lectures, the material in this latest book has apparently not been rewritten or expanded. The resulting text is well organized, succinct, and very worth reading.

The idea of an operational basis for a physical concept is enlarged to include "paper and pencil" and "verbal" operations as well as instrumental operations, which give meter readings. It is pointed out that some of our concepts include elements of all three sorts, and that it is well to recognize the distinction. In some cases, concepts have had added to their instrumental elements others which are wholly paper and pencil, for convenience alone. In others, the paper and pencil additions have led to a re-examination which has showed an instrumental significance. The choice between concepts which are instrumentally indistinguishable, differ-

ing only in the non-instrumental operations, is a matter of indifference, and is made on a basis of palatability to the user, or manipulative convenience.

The method chosen by Professor Bridgman for the presentation is by specific example. In the first lecture the concepts of field and action at a distance are compared, in the second the thermodynamic concepts of energy and entropy are treated, and the third discusses thermoelectric concepts.

Occasionally it seems that the author attributes to the proponents of such concepts as field or action at a distance a more vigorous insistence on the "reality" of their choice than we can remember experiencing since our sophomore days. But then it must be realized that the setting up of strawmen representing thinking of the past in order to show how present thinking has knocked the stuffing out is a proper concern of historians and philosophers of science.

ALAN C. BYERS

THE RISE OF THE NEW PHYSICS, by A. D'Abro. Two volumes, 1040 pages, 15 × 21 cm. New York, Dover Publications, Inc., 1951. Price, $8.00 for the set.

Beginning with the impetus given by Newton and Galileo, great advances have been made with erratic consistency throughout modern history in the physical sciences. Each period has contributed to the store of knowledge in either the field of physics or mathematics. The works of the pure mathematician and of the theoretical physicist have followed one another; in each case the mathematician has provided a means for a more complete understanding of the problems besetting the physicist. The latter part of the nineteenth century witnessed a great expenditure of effort in the development of the theoretical physics. As a consequence to this protracted period of mathematical development, the present century has produced two powerful theories of mathematical physics: The Theory of Relativity and The Quantum Theory.

In an attempt to account for certain commonplace phenomena and to extend man's understanding beyond the macroscopic world, the quantum theory was devised. Investigations of the sub-atomic world and the study of phenomena occurring under enormous pressures or at exceedingly low temperatures have been made possible with this "tool." The "New Physics" is dedicated to bring about a more complete comprehension of this theory.

Through the use of slightly under one-half a million words which are contained in forty-one chapters, the author presents a philosophical treatment of the background, development and implications of many of the theories of both classical and quantum physics. Volume I is divided into two parts: part one deals with the fundamentals of natural philosophy—emphasis being placed on its relationship to the development of the physics; part two is concerned with a review of many of the more important theories of the classical physics. Volume II is devoted to a treatment of the various quantum theories; it also contains several sections on mathematical preparation deemed necessary for an understanding of the material which follows.

Prior to presenting the theories of the quantum physics, the author covers in detail the more important theories of analytical mechanics, wave optics, thermodynamics and the kinetic theory of gasses. Starting with the original quantum theory as formulated by Planck, D'Abro follows in historical sequence the extensions and modifications to this theory. Constant comparisons are made between analyses based on extension of the classical physics and those of the quantum physics. Included in this final section are the works of Bohr, DeBroglie, Heisenberg, Schrödinger, Brone and Dirac.

Besides being a "must" for anyone doing any serious advanced study in the physical sciences, the completeness of the index causes this set of books to be an authoritative reference on the subject.

T. J. BOWDEN

PLASTICS MOLDING, by John Delmonte. 1493 pages, illustrations, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1952. Price, $9.00.

Written primarily for the plastics engineer, this book describes in some detail all the significant phases of the plastics molding industry. Production men will find the chapters on hydraulic pumps, valves, finishing accessories and instrumentation of interest. These are only

several of the chapters dealing with equipment and techniques involved in plastics molding. The molding characteristics of a large number of the commonly used plastics are described in detail, with emphasis on practical testing and specifications rather than the theoretical aspects.

Chapters on compression and transfer molding, injection molding, and extrusion are replete with photographs, diagrams, and detailed descriptions of the equipment, techniques, and limits of the equipment. For engineers in the industry and those interested in plastics molding, this book is highly recommended for its very practical handling of a large, complex division of a rapidly growing industry.

S. MUCHNICK

GEOMETRY AND THE IMAGINATION, by David Hilbert and S. Cohn-Vossen, translated by P. Nemenyi. 357 pages, illustrations, 16 × 24 cm. New York, Chelsea Publishing Co., 1952. Price, $5.00.

It is perfectly possible to render a visual presentation of geometry and in "Geometry and the Imagination" the authors have succeeded magnificently in doing just that. The various branches of geometry have been integrated in a well written book which is a distinct contribution to the American scene.

The book is profusely illustrated with excellent figures and relatively free of formulas. The illustrations are so effective that the imaginative reader can easily construct models of these figures.

The book, originally published by Springer in Germany in 1932, was translated into English by P. Nemenyi and published in this country in 1952 by the Chelsea Publishing Company.

I. M. LEVITT

ANNUAL REVIEW OF NUCLEAR SCIENCE, VOLUME I, 1952. 645 pages, illustrations, tables, 16 × 24 cm. Stanford, Annual Reviews, Inc., 1952. Price, $6.00.

"Annual Review of Nuclear Science," published by Annual Reviews, Inc., in cooperation with the National Research Council, is the first of a series of volumes to be published yearly under this title. It is essentially a review of developments in 1950 in important fields of nuclear science. The articles are by an imposing list of well-known authorities in their fields. The subjects include meson physics, several sections relating to properties of nuclei, low temperature phenomena, detection of particles, electromagnetic separation, and a good deal of chemistry of particular relevance to nuclear science. Very extensive and detailed material has been included on high energy accelerators, and there are several sections on subjects related to biology and medicine.

It is obviously impossible to make a detailed survey of all of nuclear science in a single volume, and a certain amount of selection of material has been necessary. For example, Feenberg in his article on Recent Developments in the Theory of Nuclear Structure, lists 18 topics which had to be omitted for lack of space, and the article on Progress in Metallurgy, by Rogers and Spedding, had to be limited to a high-light review of subjects related to nuclear science.

Despite the conciseness imposed by limitations of space, however, the articles are not merely listings of the published literature. On the contrary, they are sufficiently expository and contain enough background material to be comprehensible to readers having a general acquaintance with the subject.

It is a truism that the day has long passed when one man could comprehend all scientific knowledge. The vast quantity of information that has made our time an age of specialists has posed the problem of making the knowledge of one specialist available to another. "Annual Review of Nuclear Science" is a valuable aid to this end.

GEORGE PETER WACHTELL

THE AUGER EFFECT AND OTHER RADIATIONLESS TRANSITIONS, by E. H. S. Burhop. 188 pages, plates, diagrams, 14 × 22 cm. New York, Cambridge University Press, 1952. Price, $5.50.

The Auger effect may be briefly described as follows: a neutral atom is ionized by the ejection of an electron from an inner shell, and the atom has an elevated energy depending on

the level from which the electron was ejected. A transition may occur in which an electron from an outer shell fills the inner vacancy, and radiation takes place at a frequency depending on the difference between the energies of the two levels. On the other hand, a radiationless transition may occur instead, where the energy is communicated to another electron of the same atom and this electron is ejected. This radiationless reorganization of an atom ionized in an inner shell is called the Auger effect in recognition of the work of Auger (1925) who first interpreted the paired tracks in the Wilson cloud-chamber in terms of this effect.

Thus the Auger effect is due to a radiationless reorganization of an atom. There is an alternative explanation of the effect as an internal conversion process, whereby a quantum of X-radiation is first produced, and then absorbed by an electron of the atom in which it originated before the radiation has a chance to escape. The book gives an analysis of both these theories. This is followed by a chapter on the experimental study of the Auger effect.

The importance of the Auger effect in the study of X-ray spectra and in the study of the capture of mesons by nuclei are treated. There are chapters on the internal conversion processes in the creation and annihilation of electron pairs. The book concludes with a discussion of radiationless transitions in atomic and molecular spectra.

The book gives a rather complete discussion of most of the work in this field up to December 1950. It should be of particular value to workers in the fields of nuclear and X-ray physics.

H. PLATZER

BOOK NOTES

ELECTRICAL ENGINEERING: THEORY AND PRACTICE, by W. H. Erickson and N. H. Bryant. 523 pages, diagrams, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1952. Price, $6.00.

Two Cornell faculty members offer this new text on electrical engineering, stressing analysis and study rather than "formula substitution." It was used in mimeographed form for several years in a sequence of three 3-semester hour courses for mechanical, civil and chemical engineers, and has also been used successfully in a sequence of two 4-hour courses. Three general topics are covered: circuits, machines and electronics. It is a good basic text for non-electrical engineering students, covering all the necessary fundamentals in a clear understandable style. The physical, rather than the purely mathematical, approach is emphasized—which results in the omission of certain topics, such as the equivalent-circuit concept for a-c. machines. The problems appended to each chapter are practical, requiring analysis rather than the memorization of formulas. The 325 diagrams and figures add clarity to the presentation.

CHARTING STATISTICS, by Mary Eleanor Spear. 253 pages, charts, illustrations, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1952. Price, $4.50.

For those authors, teachers and lecturers who must use statistics and are looking for the best way to put those statistics in graphical form, this new book should be a gold mine. The author analyzes various kinds of charts, makes suggestions as to what type of chart to use in particular problems, and shows how to break down data to emphasize a particular fact. The book is highly practical, profusely illustrated, and very concise. In these days of visual education, this book should be studied by all who wish to get a difficult message before the public in such a way that it will be remembered.

STRENGTH OF MATERIALS, by Frank J. McCormick. 177 pages, diagrams, 16 × 24 cm. New York, The Macmillan Company, 1952. Price, $3.75.

Written primarily as a one-semester text for third and fourth year students of architecture and industrial arts, this new book on the strength of materials emphasizes beam deflections, using the conjugate beam method. Amply provided with worked out examples and problems (with answers), the text should prove easy to use in the classroom. The material can be taught to students with no more advanced mathematics than trigonometry.

BLAKISTON'S ILLUSTRATED POCKET MEDICAL DICTIONARY, edited by Normand L. Hoerr, Arthur Osol, S. W. Chase, C. C. Francis, M. G. Howell and L. E. Moore. 1032 pages, illustrations, 13 × 18 cm. New York, The Blakiston Company, 1952. Price, $3.25 (plain); $3.75 (thumb-indexed).

Full, unabridged definitions of more than 33,000 medical terms are listed in this new dictionary, in spite of its small size. Twenty four plates, sixteen in color, enhance the usefulness of the book, as do the many tables listing the arteries, bones, muscles, nerves, veins, etc. Definitions are cross-referenced to these tables, grouped in the appendix for easy use. Including, as it does, the most up-to-date medical terms, this dictionary should be most helpful to nurses, laboratory workers, medical social workers, lawyers, public health officers and reporters.

PRACTICAL CALCULUS, by C. I. Palmer and Claude E. Stout. Second edition, 470 pages, diagrams, 12 × 19 cm. New York, McGraw-Hill Book Co., Inc., 1952. Price, $6.00.

Palmer's standard manual on how to use calculus in practical problems has been revised by C. E. Stout, of the General Motors Institute. Retaining the original purpose of providing a simple practical treatment of the calculus, this second edition adds new material on: Newton's method of approximating the solution of a numerical equation; approximate integration; differential equations; cylindrical and spherical space coordinates; and equations and graphs of the more common surfaces in rectangular coordinates.

CORRECTION: "Du Pont—The Autobiography of an American Enterprise," was incorrectly listed as "not for sale" in our September Book Notes. The volume is on sale at Charles Scribner's Sons, New York, or at leading bookstores, for $5.00 a copy.

THE FRANKLIN INSTITUTE

exists today because of the faith and generosity of the men and women who for 128 years have given time and money to its support.

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FORM OF BEQUEST

*I give and bequeath to The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, the sum of*_____

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, DIRECTOR

Pepsin Inactivation by Inert Gases.—GEORGE M. NAIMARK* AND WILLIAM A. MOSHER. It is well known that soluble globular proteins spread on quiescent gas-liquid interfaces to form two-dimensional monomolecular films of unfolded molecules. Since the bubbling of a gas through a liquid results in the rapid formation and collapse of gas-liquid interfaces, it is to be expected that such treatment would result in the denaturation and subsequent inactivation of protein enzymes.

It was found that the bubbling of argon, nitrogen or an argon-butane mixture through solutions of low concentration (0.2 per cent) of U.S.P. Merck Pepsin resulted in the rapid inactivation of the enzyme. An atmosphere of inert gas was not sufficient to cause inactivation. The inactivation caused by gas bubbling was not reversed by prolonged standing and was not due to the introduction of impurities by the gas.

We are led to conclude that gas bubbling provides gas-liquid interfaces upon which the enzyme spreads and forms monomolecular films. The collapse of the bubbles crushes the films and mechanically alters the protein structure. This type of enzyme inactivation is therefore the result of surface denaturation followed by the destruction of the formed films and is an irreversible reaction.

* Present address: Strong Cobb and Co., Inc., 2654 Lisbon Road, Cleveland 4, Ohio.

CURRENT TOPICS

Surgery in Your Living Room.—"You are looking over the shoulder of Dr. Samuel Fogelson, while he operates on a patient in the Wesley Memorial Hospital in Chicago. As he teaches other doctors by television new surgical techniques that are helping to increase our life span, he symbolizes for all of us the march of medicine."

With these dramatic words, television, serving as the eyes of more than five million watchers from coast-to-coast, moved down over the operating table to show the skilled hands of a surgical team performing the difficult procedure for the removal of a stomach.

With this event, put on in cooperation with the AMA by the pharmaceutical manufacturing firm, Smith, Kline & French Laboratories, television in America reached a maturity undreamed of but a few years ago. Through its all-seeing and uncompromising eye, the television camera moved in on one of the most sacrosanct of assemblies in the entire country, the annual conclave of the American Medical Association. Its piercing eye roved with openness and frankness about the exhibit hall of the convention, showing sometimes unpleasant sights, but always revealing the facts of medical progress.

Under the symbolic title of "The March of Medicine," the two television reports of the world's largest medical meeting were brought to the public with Dr. Roy K. Marshall ("The Man Who Makes Science Easy") serving as a guide. Their subject matter ranged from a sane, unhysterical discussion of the new "TB drugs" to a demonstration of new heart-lung apparatus. Overweight, infantile paralysis, cerebral palsy, new methods of manipulating artificial limbs, new methods of portraying and recording important heart sounds, a new technique of artificial respiration, a new "lung penicillin" called Neo-Penil, a new "way of life" for cripples and heart disease victims—these were the vital subjects surveyed by the television cameras, advances which demonstrated how the medical profession is working to give the nation the best health care in the world.

Of all the mysteries unveiled, it was the surgical operation that aroused the most interest and provoked the greatest controversy. As Dr. Fogelson and his operating team calmly carried out their delicate surgical mission on the ulcer patient, they probably knew that the event would raise a great debate. It did. Even officials of the AMA questioned the propriety of the public telecast of surgery, and the British Medical Journal opined that "relays direct from the operating theater should be banned as unsuitable entertainment." American television critics either praised or questioned the surgical telecast, and predicted the displeasure of the medical profession.

But the medical profession and the general public took the event in their stride. No public outcry came forth from Mr. and Mrs. America, and the instigators of the event reveal that a searching survey found the medical profession overwhelmingly enthusiastic about the March of Medicine telecasts.

But though the ulcer operation stole the "March of Medicine" spotlight, the program brought other medical news to the American public.

Every day during the week-long convention, actual demonstrations of new

life-saving rescue and artificial respiration techniques were held off the end of Navy Pier for the 14,000 doctors at the convention. An actual re-creation of these demonstrations led off one of the most interesting demonstrations of the network telecasts.

As the TV cameras recorded the procedure, Dr. Archer S. Gordon of the Los Angeles County General Hospital demonstrated the new "back-pressure, arm-lift" method of resuscitation. Explained Dr. Carl Potthoff, of the American National Red Cross, "This method is superior to the old Shaeffer method because it provides two to three times as much air ventilation as the Shaeffer method did, and it is particularly useful to patients who are most deeply asphyxiated and need air most."

In a rational discussion of the new "miracle" anti-TB drug, isonicotinic acid hydrazide, Dr. DuMont Elmendorf of New York Hospital showed X-rays of typical cases and pointed out that while "it helps people who are acutely ill with tuberculosis, it does not help those who are chronically ill to a great extent," and that "not all patients can be cured, and other forms of therapy such as rest and surgery are still very important."

A new drug for non-tuberculous lung conditions was described as "a definite advance in penicillin therapy and opens up a new field in penicillin treatment," in the words of Dr. Harrison Flippin of the Philadelphia General Hospital, who was interviewed by Dr. Marshall on the new "lung penicillin" called Neo-Penil.

To show advances in care of infantile paralysis victims, Dr. Hart E. Van Riper of the National Foundation for Infantile Paralysis demonstrated various forms of iron lungs, from "the oldest machine that we have used" (since 1929) to "this so-called portable or chest respirator that has many advantages over the iron lung, but will never replace it," and even "the rocking bed, which you see gives the patient even more freedom than the chest respirator."

Three little children from the Cerebral Palsy Clinic of Milwaukee were portrayed carrying out special therapeutic exercises under the guidance of physical therapists, a demonstration which Dr. Marshall termed a source of "very very great hope."

The threat of overweight as "the nation's Number 1 health problem" was brought to the attention of the cross-country television audience by Dr. Louis I. Dublin of the Metropolitan Life Insurance Co. And Oliver Field, of the AMA's Bureau of Investigation, warned the viewers of the fallacious weight-removing methods which are so flagrantly advertised to gullible overweight persons.

The fact that medical practice is much more than surgery and pills was shown by two demonstrations of novel kitchens designed for wheelchair and heart patients. Dr. Howard A. Rusk of the Institute of Physical Medicine and Rehabilitation of the New York University-Bellevue Medical Center—and well-known medical columnist of the *New York Times*—took Master-of-Ceremonies Roy Marshall on a tour of a kitchen specially designed for handicapped patients. He demonstrated many simple devices for making kitchen work easier, down to "my favorite, a wastecan which as you see is operated simply by running the wheelchair over this lever."

Also in the heart line was a demonstration of a new method of recording the heart beat on an oscilloscope and tape recorder, to give a simultaneous picture and sound of the heart beat. The device was demonstrated by Dr. J.

Scott Butterworth of the New York University Postgraduate Medical School. Finally, Dr. Anna Sirek of the University of Toronto was pictured by her "Rube-Goldberg" heart-lung apparatus, a complex device of tubing and pumps which takes over the function of those critical organs during difficult surgical procedures.

Fourteen thousand doctors attended the Chicago session. But through television a total audience of more than 7,000,000 was able to step inside and personally observe the reports of medical advances.

Smith, Kline & French's closed-circuit color television programs, at 40-odd medical meetings over the past three years, had pioneered in the partnership between medicine and television. A doctor-audience of some 250,000 had been taught by television.

But with "The March of Medicine," medical television became the servant of the millions, a mature medium bringing important information to an ever-maturing audience.

Electronic Motion Analysis.—Under the direction of Prof. Karl U. Smith, psychologists Gerald Rubin, Robert Smader, Shelby Harris, and Richard Simon are making a scientific study of the various motions that go into simple and complex tasks, and electronic devices are saving them thousands of hours of time and millions of feet of motion picture film—the traditional tool used by scientists in the study of moving objects.

"Since early in the century, science and industry have depended upon high speed motion picture photography to analyze the detailed movements involved in human motions of work or skill," Prof. Smith points out. "Now methods have been devised to study the movements and position of the hand as it grasps and turns the knobs of a control panel, and as it performs assembly tasks and operates machines."

To make these studies possible the UW scientists have invented a number of electrical devices in which a human subject acts as a key. As he conducts his assigned task, he opens and closes various electrical circuits which time each movement.

Most studies made with the electronic tools at Wisconsin would otherwise require several million frames of motion picture film to obtain the same information.

"The electronic methods of motion analysis can be used to investigate the validity of principles of time-study used in industry," he continues. "These principles have never been subjected to careful scientific scrutiny, even though industry is turning more and more to methods for study of human motion in setting up work standards and wage incentives."

One of the important things so far discovered is that the same movement in different work situations is apt to take different periods of time—thus upsetting an old time-study rule of thumb.

The new electronic devices may be used for diagnosis of some neurological disorders, particularly those which have a destructive effect on hand or foot movement, Prof. Smith says.

The motion analysis methods have also made it possible to study such problems of human motion as the effect of fatigue and interruptions upon individual movements in particular skills.

"Learning the motions involved in assembly tasks, in such things as track-

ing—like driving a car—and in operating machine controls is mainly an improvement of hand manipulation. The travel movements of transferring the hand from one place to another in these tasks are not improved much, if at all, by learning," Prof. Smith reports.

Experiments also show that learning does not actually result in the creation of any new relationships between the many movements required for a task—instead, each movement remains a kind of separate event even after long periods of practice.

"In producing skilled movements, the human body acts like a many-channeled system, producing a variety of specific movements that have significance in the various tasks that must be performed," Smith says. "Although everything in the modern world depends upon skilled hand movements, there exists no systematic science of how the human hand performs its skills."

Prof. Smith points out that many persons have had the disturbing experience of changing from the old style gear shift to one on the steering shaft of modern cars.

"Motion analysis studies show there are strange effects when movements are transferred from one pattern to another. The interference effects of previous learning will carry over for long periods of time—which probably accounts for the difficulties of teaching old dogs new tricks," Prof. Smith says.

Weather Prediction by "Radioactive" Pen.—A pen that writes the weather has proved an accurate means of detecting atmospheric changes for General Electric Company scientists.

The device puts down on paper weather changes ranging from distant summer showers to onrushing thunderstorms.

With the aid of a radioactive point on a slender shaft mounted atop the G-E Research Laboratory, scientists are gauging the electrical activity generated by weather changes as slight as shifting winds. Even variations in intensity of light reflected from clouds sometimes register noticeable changes on the recording mechanism.

Electric current, collecting on the radioactive point from high potential developed between earth and atmosphere, is measured by an extremely sensitive G-E photoelectric recorder located in the laboratory's penthouse weather station.

The tiny stylus of the apparatus moves left when negative charges grow on the antenna outside. Positive charges move the pen to the right. Dead center is zero potential on the paper chart moving steadily past the red-writing stylus.

With clear skies overhead, small deflections of the delicate instrument correlate well with the outbreak of showers within a radius of 450 miles, according to Raymond E. Falconer, G-E meteorologist working on the apparatus.

On clear days, he points out, the pen stays close to the center line of the chart. But radium-impregnated gold foil on the antenna has made it so sensitive the pen seldom remains at rest.

When thunderstorms move into the area, the pen springs to life. The approach of a storm consistently builds up a negative charge, sending the thin red line far to the left on the ruled paper.

Lightning flashes reverse the pen. It moves quickly to zero, and at times swings over to a positive position. The approach or passage of cold and warm

fronts write easily identified patterns on the chart. A build-up on the negative side usually heralds a warm front. A positive reading in most cases identifies the cold.

Freezing and sublimation (the direct conversion of vapor to ice) usually register a positive pattern. Melting and condensation touch off negative activity in the atmosphere.

Advantages looked for by Falconer in the more widespread use of the weather device include closer pin-pointing of cold and warm fronts on the weather map. It also can be used to indicate the presence of fronts high in the atmosphere which otherwise might go undetected. Falconer pointed out, too, that pen strokes across the chart can be used to count lightning flashes in the area.

Sharper short-range weather forecasts may result from the use of networks of these devices in weather stations across the country, he believes.

The mechanism ferrets out isolated showers and disturbances not otherwise detected by most instruments now used in ordinary weather stations, he said.

According to Falconer, the equipment can tip off weather men about the presence of disturbances which could be found otherwise only by radar. The G-E device, he pointed out, costs only a fraction of the price paid for radar equipment.

Work with the equipment was started in 1943 by Dr. Vincent J. Schaefer, the G-E scientist who discovered that artificial seeding of clouds could cause rain.

Computer Manufacturer Offers Engineering Service.—The Computer Corporation of America has inaugurated a service which furnishes solutions to complex problems in dynamics for industrial organizations, government bureaus and researchers. The new service, according to a company spokesman, should prove useful for qualitative and quantitative studies in aerodynamics, servo-analysis, mechanical engineering, chemical processing, thermodynamics and many other fields. Such studies can determine optimum specifications for a single component or a total dynamic system. The Computer Corporation of America, manufacturer of the "IDA" analog computer, points out that problems will be accepted for analysis and solution whether the use of a computer is required or not.

Inquiries should be addressed to Computer Corporation of America, 149 Church Street, New York 7, N. Y.

Electrically Lighted Industrial Magnifier.—An electrically lighted magnifier for general industrial use has been announced by Bausch & Lomb Optical Co., Rochester, N. Y. The instrument is designed to speed detailed examination of all kinds of materials and products through self-contained direct illumination on the object. It comes equipped with either of two types of illuminator handles, one battery-powered, the other for connection with a 110-volt power source. Either handle fits a reflector-type shade into which the magnifier snaps. Accessories furnished without extra cost are a non-illuminating handle and a metal tripod, which multiply the uses of the magnifier.

The instrument's lens system magnifies five times and is highly corrected to eliminate virtually all spherical and chromatic aberration and distortion. It has a wide, flat field.

In using a magnifier, provision of an adequate light supply on the object has been a problem in the past. This problem is effectively met by the self-contained illumination which floods the object with direct light, according to designers of the new instrument.

Evaporation Technique is Key to Adhesion Studies.—Evaporation techniques for the adhesion of electroplatings and solders to oxide-coated metals and glass have shown great progress at the Engineer Research and Development Laboratories, Fort Belvoir, Va.

Some metals are difficult to electroplate or solder due to poor adhesion to their natural hard tenacious oxide coatings. When these coatings are removed new oxides are immediately formed. Metals such as aluminum, chromium and titanium become coated with an oxide film even at room temperature in a vacuum at pressures less than 10^{-5} mm. Hq. Hence, it is desirable to secure adhesion to these metals by a process which includes their oxides. Excellent adhesion to these oxides can be obtained by high vacuum evaporation techniques. Evaporated films of most metals that form hard adherent oxide coatings can be caused to adhere tenaciously to their own and to other oxides, including glass. Evaporated films of some other metals, particularly gold, silver and copper show poor adhesion to oxides. However, a metal of the latter group can be made to adhere tenaciously to a metal of the former group by high vacuum evaporation techniques. The vapors of the two metals can be deposited simultaneously in such a manner as to eliminate the oxide coating which normally hinders adhesion. Thus, to coat titanium with copper, titanium is first evaporated on the oxide-coated titanium. At the first evidence of titanium deposition the evaporation of copper is begun. At the first copper deposit the titanium source is turned off and the copper evaporation continued until no titanium shows through the surface. The resulting surface can be soldered to directly or can be built up by electroplating. This method can be adopted to coating rolls or flat plates in a continuous coater.

Responsible for the investigations on adhesion of evaporated coatings is Mr. Noel W. Scott, Physicist in the Engineer Research and Development Laboratories, Radiation Branch, Fort Belvoir, Virginia. Referring to this new process Mr. Scott said that outgrowths of the studies demonstrated that ". . .evaporated coatings can be used to advantage in processes for applying heat resistant coatings to metals, transparent conducting coatings to glass, and the manufacture of mirrors by a replica technique."

Plastic ships and airplanes are being put through tests at the David Taylor Model Basin, where wind tunnel and model basin tests show that they are better suited for experimental use than are the traditional wood or wax models. Plastic models are lighter and stronger, allowing more space for interior mounted test instruments. With color added to the plastic, painting of the model is eliminated. Plastic models pick up less moisture from air and water, retain original accurate dimensions longer. Production of a number of identical models is simplified, and cost greatly reduced, by preparing a mold which turns them out as needed.

Automatic plotting of digital solutions is performed by a "teleplotter" now installed at the Naval Ordnance Laboratory, White Oak, Md. Among its

other abilities,"teleplotter" can plot missile trajectories and compute the path of yaw without the missiles actually being fired. The machine will help engineers plan test programs with 90% reduction in time required for interpretation of data, will also tell whether formulation of a problem is right and whether instruments worked properly during test. Control circuits of the machine, which uses 600 electronic tubes, were worked out by personnel from NOL and the IBM Corporation.

High-Altitude Research Facilities Available.—The White Mountain Research Station on Mount Barcroft, California, in the White Mountain range near the California-Nevada border, is expected to become one of the leading high altitude research laboratories on the North American continent under a program of joint support by the National Science Foundation, the Office of Naval Research and the Rockefeller Foundation. The three agencies have obligated themselves to provide combined support totaling $36,000 per year for a three-year period.

The laboratory, open to any scientist requiring high-altitude research facilities, is under the direction of Professors Nello Pace and S. F. Cook of the Division of Physiology of the University of California. The University assumes responsibility for maintenance of the facilities under the program. At the present time, Drs. Pace and Cook are assisted by an interdepartmental committee, composed of University of California staff members representing the various disciplines of the biological, medical and physical sciences. It is intended that this advisory committee will be broadened to include scientists from all geographical regions of the United States and from the various fields of science which require high altitude research facilities.

Facilities at White Mountain now available to scientists include a center at the 10,500 foot level and another at 12,500 ft. In addition, limited experimentation may be carried on at heights up to 14,256 ft., the peak of White Mountain itself. This point is readily accessible at a distance of 3 miles from the upper laboratory. Living quarters and laboratory space are available at both the 10,500-ft. and 12,500-ft. levels. A colony of small laboratory animals is presently being maintained at the 10,500-ft. level.

Ship borne oxygen generating plants developed under a Bureau of Ships program will make aircraft carriers self-sufficient in providing oxygen for jet plane operation. The plants produce 500 cu. ft. of gaseous oxygen, 1,500 cu. ft. of gaseous nitrogen per hour; the oxygen is used by high-flying jet pilots while the nitrogen, a by-product, is used for purging gasoline lines. Great weight reduction is a valuable feature of the plants which weigh only 20,000 lb., produce in only five days oxygen enough to fill 70,000 lb. of empty compressed gas cylinders.

Industrial Stereomicroscope.—A free consulting service through which production and inspection supervision can explore new concepts in optics for industry has been offered by Bausch & Lomb Optical Co., Rochester, N. Y., in connection with its new Industrial Stereomicroscope.

Through this service, Bausch & Lomb representatives will demonstrate how various models of the new instrument can be built into machine, assembly, and inspection set-ups to speed processing, reduce rejects, and diminish employee fatigue.

The instrument, embodying latest advances in industrial optics, is available in a large range of wide field objectives and wide field eyepieces to provide the variety in size of field, working distance, and magnification needed for the newest specialized factory applications.

A typical combination of wide usefulness, for instance, would be a 1.0 objective in combination with a 10 eyepiece, which would give 10 magnification with a 0.79-in. field and a 3.77-in. working distance.

Through other combinations, magnification up to 150 is possible.

The microscope was designed in response to demands from industry for an instrument which could cope with the ever-increasing precision of working tolerances, according to James R. Benford, head of the Bausch & Lomb microscope design department.

"In the last 15 years, working tolerances of .0001 inches and less have become almost commonplace instead of the rarity they used to be," Benford pointed out. "This has resulted in a need for increased use of optical instruments in both manufacturing and inspection."

The industrial stereomicroscope permits comfortable observation of an enlarged image with a wide field of view, long working distance and three-dimensional, easily-interpreted qualities. When built into a machine, assembly, or inspection set-up, it provides for continuing observation of the operation so that manufacturing and inspection standards can be adhered to, especially in such processes as fine machining, assembling of minute parts, and making tiny welds in electronic wiring.

It embodies vertical eyepiece tubes with adjustments for interpupillary distance and balancing acuity of the observer's eyes, binocular dustproof prism bodies, and illuminator socket.

Framing Anchors as Joist Hangers.—Instructions on the use of Trip-L-Grip framing anchors as joist hangers are detailed in a new folder being distributed to architects and home builders by Timber Engineering Company, affiliate of National Lumber Manufacturers Association.

Although the anchors are designed for all secondary connections in wood frame construction, they have their largest use as joist hangers because of resultant economies in time, labor, materials and space. They are adjustable, on the job, to joists of uneven width and depth, and can be applied before installation. They eliminate ledger strips and all notching, fitting and shimming of joists, and do away with old-fashioned toenailing of other connections.

An increasing use of these framing anchors is in clear span construction with trussed rafters. By placing the anchors in position on the plate in advance, the trussed rafters are erected more quickly and easily.

Detail drawings of other uses of the anchors are included in the folder, copies of which may be obtained on request to Timber Engineering Company, 1319 18th Street, N. W., Washington 6, D. C.

Flying Saucers.—An electrical discharge phenomenon produced in a vacuum bell jar at the Engineer Research and Development Laboratories, Fort Belvoir, Va., may be a possible solution to the mystery of "flying saucers," according to Noel W. Scott, physicist.

Working with the vacuum bell jar on experiments in mirror and lens coat-

ing, Mr. Scott produced an eerie orange object that bears a striking similarity to the "flying saucers" that many claim to have seen.

For the press, Scott demonstrated the "saucers" and made them behave very much like the real thing. He pumped air out of the bell jar to create a partial vacuum. The air left in the jar was electrified by discharge between highly charged electrodes. He then introduced air from the outside which caused a relatively bright glow to form on some portions of the positive electrode. By varying the amount of air introduced into the jar the color of the "saucers" varied from orange-red to purple, pink to white. The introduction of helium into the chamber produced a green "saucer."

The "saucers" were produced in many of the shapes that have been sighted to date. A wave of a magnet outside the jar and the laboratory-made "saucers" skirted elusively about the rim of the jar, stood still, reversed their fields and in general behaved very much like the real things are said to behave. "The saucers," Mr. Scott said, "remain stationary, move at an excessive rate of speed or change direction almost instantly by altering the direction and intensity of the rays and the electric and magnetic fields, and by changing the atmospheric pressure." This may explain why airplanes, attempting to fly near them, have failed in detecting or sighting them. Once any factor responsible for the formation of this phenomenon is changed, the "saucer" might completely engulf an object, attach itself to it, repel it or fade out completely. Scott also stated the "saucers" have enough substance to cause "blips" and be picked up on radar screens.

Scott said he came upon the "saucers" quite by accident and does not offer this explanation as the only answer to the nationwide "saucers" problem. "It is just one theory," he said, "and not even a new one at that." This theory—the ionization or electrification of air—is well known in science and has been advanced before. Actually, what Mr. Scott did was associate this theory with the "flying saucers" mystery that has kept the nation guessing since 1947. He did this by producing on the laboratory level, a phenomenon peculiar to the upper atmosphere.

"Flying saucers" are thought to possess the same family characteristics as other illuminating atmospheric phenomena. Mr. Scott said, "they probably lie somewhere between the two extremes of streak lightning and the multicolored Aurora Borealis."

During the several demonstrations for television, magazine, newspaper and newsreel companies at the Engineer Research and Development Laboratories, Mr. Scott repeatedly stated: "The atmospheric conditions necessary for producing this phenomenon are not the *prevailing* conditions that exist in the upper atmosphere. However, it is not altogether improbable that there may be 'occasional' local conditions responsible for this glow which might be interpreted as 'flying saucers.' "

Hen's Egg Playing Important Role in Fight Against Rabies.—The common, everyday hen's egg, so popular on America's breakfast tables, is playing a vital role in medical science's efforts to eradicate rabies and other virus-caused diseases. You may like your eggs sunny-side-up, soft boiled, or poached, but scientists at Lederle Laboratories like theirs embryonated. No, that's not a new omelette; it's an egg with a living embryo. In fact, they like these eggs so well that they have used as many as 12,000,000 a year.

From these embryonated eggs are produced modified live virus vaccines for immunizing dogs against rabies and distemper, mink against distemper, and poultry against several killing diseases.

The canine rabies vaccine made from embryonated chicken eggs is the most effective agent yet developed for preventing this horrible disease. Tests are under way to prove that dogs vaccinated with a single injection of this vaccine have lifetime immunity against rabies.

The whole thing started in 1911, when a researcher discovered that he could breed and attenuate (weaken) a "hot" virus strain by numerous passages through embryonated eggs. This was the beginning of an entirely new field of research in viruses, for the egg provided an economical medium, which is in constant supply, for modifying virus strains for vaccines. Previously, anti-rabies vaccines for animals had been prepared by taking the brains and cords of large domestic animals that had been infected with rabies. This tissue, containing rabies virus, was prepared for use as a vaccine by treating with certain chemicals. Not only was this vaccine painful and expensive, but occasionally the vaccine itself crippled or more rarely killed the animal. And these inoculations had to be repeated every year.

The egg, in the hands of virus scientists here, is changing this. Through years of painstaking research, they have developed a modified live virus vaccine that will protect against rabies, but is not potent enough to cause an outbreak of the disease.

A similar story is revealed in the case of canine distemper, most common serious disease of dogdom. Regardless of how careful an owner is, all dogs are susceptible to this virus-caused ailment. This virus strain, also, has been modified in the hen's egg to the point that it will prevent distemper and not make the animal sick.

It is only right that chickens should benefit from their handiwork. Vaccines for three deadly poultry diseases—fowl pox, Newcastle disease, and fowl laryngotracheitis—are produced in embryonated hen's eggs. So in one sense, you can say that the egg is protecting and insuring future generations of eggs. These three diseases, all caused by filterable viruses, annually inflict millions of dollars in losses among the nation's chicken and turkey crops.

Efforts are being made here to grow other deadly viruses, such as that which causes poliomyelitis, in the chicken's egg, but so far the scientists have met with little success.

Production of these vaccines, now that the years of hard research and millions of dollars have been spent, seems like a simple thing. The procedure is this: a skilled worker uses a dentist's drill to make a tiny hole in the shell of the fertile egg, taking care not to break the membrane. Through this opening, some of the live virus is injected with a needle, and the hole is immediately sealed with collodion. The eggs are then placed in a huge incubator and the virus allowed to multiply. Before hatching, the shells are tapped and the tissues removed. From these the vaccines are made. It's a long and tedious process, since each one of the millions of eggs used every year has to be handled individually.

Scientists here believe that the egg is one of the best mediums ever discovered for growing modified viruses, and many feel confident that other virus strains will be adapted to the egg in man's continuing effort to "tame" deadly viruses which can't be seen, but which kill at an amazingly high rate.

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